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UNMANNED EVALUATION OF U.S. NAVY UBA EX-16 PROTOTYPE CLOSED CIRCUIT REBREATHER

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December 1979

Approved for public release; distribution unlimited

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Exhalation
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Breaths per minute (BPM)
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The Navy Experimental Diving Unit (NEDU) evaluated the prototype U.S. Navy Underwater Breathing Apparatus EX-16 in the following configurations: (1) standard hoses with MK-6 mouthpiece; (2) enlarged breathing hoses with MK-6 mouthpiece; and (3) enlarged breathing hoses and the AGA full face mask. A series of unmanned tests was conducted to determine performance characteristics of the various EX-16 configurations. Data derived from

(Continued)

these tests will be used in follow-on development and testing of the EX-16 UBA. Results indicate the AGA full face mask with its larger breathing hoses to be the optimum combination for low diver respiratory work. The scrubber canister design is deemed adequate and further modifications are unnecessary.

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ABSTRACT

The Navy Experimental Diving Unit (NEDU) evaluated the prototype U.S. Navy Underwater Breathing Apparatus EX-16 in the following configurations: (1) standard hoses with MK-6 mouthpiece; (2) enlarged breathing hoses with MK-6 mouthpiece; and (3) enlarged breathing hoses and the AGA full face mask. A series of unmanned tests was conducted to determine performance characteristics of the various EX-16 configurations. Data derived from these tests will be used in follow-on development and testing of the EX-16 UBA. Results indicate the AGA full face mask with its larger breathing hoses to be the optimum combination for low diver respiratory work. The scrubber canister design is deemed adequate and further modifications are unnecessary.

GLOSSARY

BPM	breaths per minute
Canister Breakthrough	point at which CO_2 concentration in the breathing gas reached 0.5 percent surface equivalent
°C	temperature in degrees Centigrade
cm H_2O	centimeters of water pressure (differential)
CO_2	carbon dioxide
EDF	Experimental Diving Facility
EOD	Explosive Ordnance Disposal
°F	temperature in degrees Fahrenheit
FSW	feet of seawater
H.P. Sodasorb	high-performance Sodasorb
kg.m/l	work of breathing in kg.m per liter of ventilation
LPM	liters per minute (flow rate)
NEDU	Navy Experimental Diving Unit, Panama City, Florida
O_2	oxygen
P_{O_2}	partial pressure of oxygen
ΔP	pressure differential (cm H_2O)
psig	pounds per square inch gauge
RMV	respiratory minute volume in liters per minute
S.E.	surface equivalent
TV	tidal volume (liters)
UBA	underwater breathing apparatus

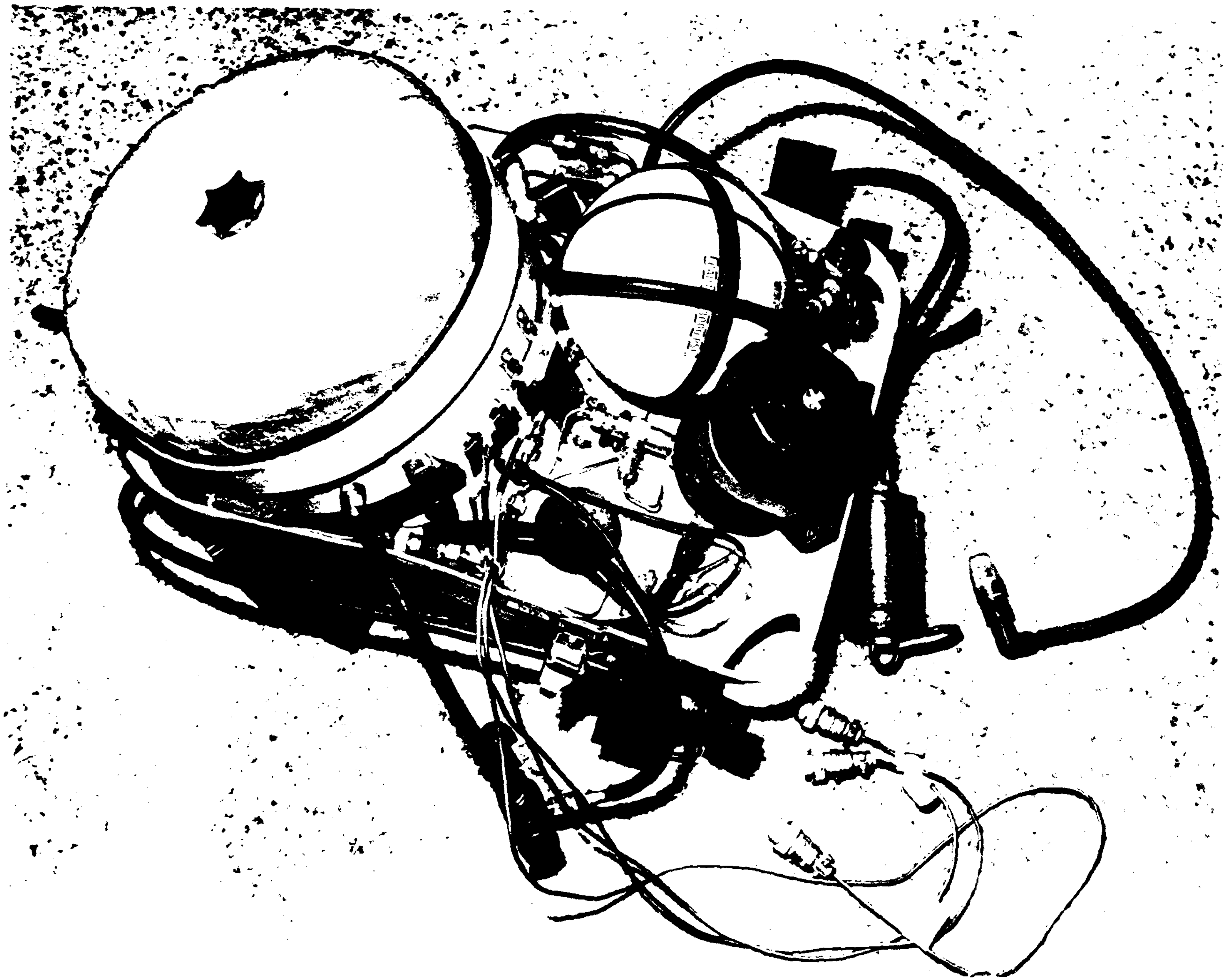


Figure 1. PROTOTYPE EX-16 UBA BACKPACK

INTRODUCTION

Unmanned testing by NEDU in March 1979 evaluated the prototype U.S. Navy UBA EX-16 Closed Circuit Rebreather in three configurations:

(1) Standard breathing hoses with MK-6 mouthpiece

(2) Enlarged breathing hoses with MK-6 mouthpiece

(3) AGA full face mask with enlarged breathing hoses

The purpose of these tests sought to establish performance characteristics of the various EX-16 configurations at depth and at varying water temperatures.

EQUIPMENT DESCRIPTION

The EX-16 (figure 1), an EOD variant of the MK-15 family of closed circuit rebreathers, derives its current title from the anticipated future designation of the rig as the MK-16 UBA.

The EX-16 is a closed circuit, mixed-gas, self-contained underwater breathing apparatus. A battery-operated electronic module maintains the swimmer's breathing gas at a predetermined partial pressure of oxygen (P_{O_2}) via three oxygen sensors which measure and evaluate the P_{O_2} level. When an O_2 deficiency is indicated, the electronic module activates the piezoelectric crystal in the oxygen pressure system to add O_2 to the breathing circuit. The principal difference between the EX-16 and the MK-15 Mod 0 configuration is found in the nonmagnetic properties of EX-16 components. The O_2 add valve of the MK-15 has been replaced by a piezoelectric crystal which incorporates a non-acoustic feature. In addition, the CO_2 scrubber assembly of the EX-16 uses Lexan materials, rather than metal. The EX-16 canister is also replenished with CO_2 absorbent through the top, rather than the side opening of the MK-15 canister.

FUNCTIONAL DESCRIPTION

Location, function, and interrelationship of the four subsystems comprising the EX-16 are identical to the MK-15 Mod 0 UBA (see *Chapter 3, Operation and Maintenance Instructions, UBA MK-15 Mod 0, NAVSEA 0994-LP-016-1010*).

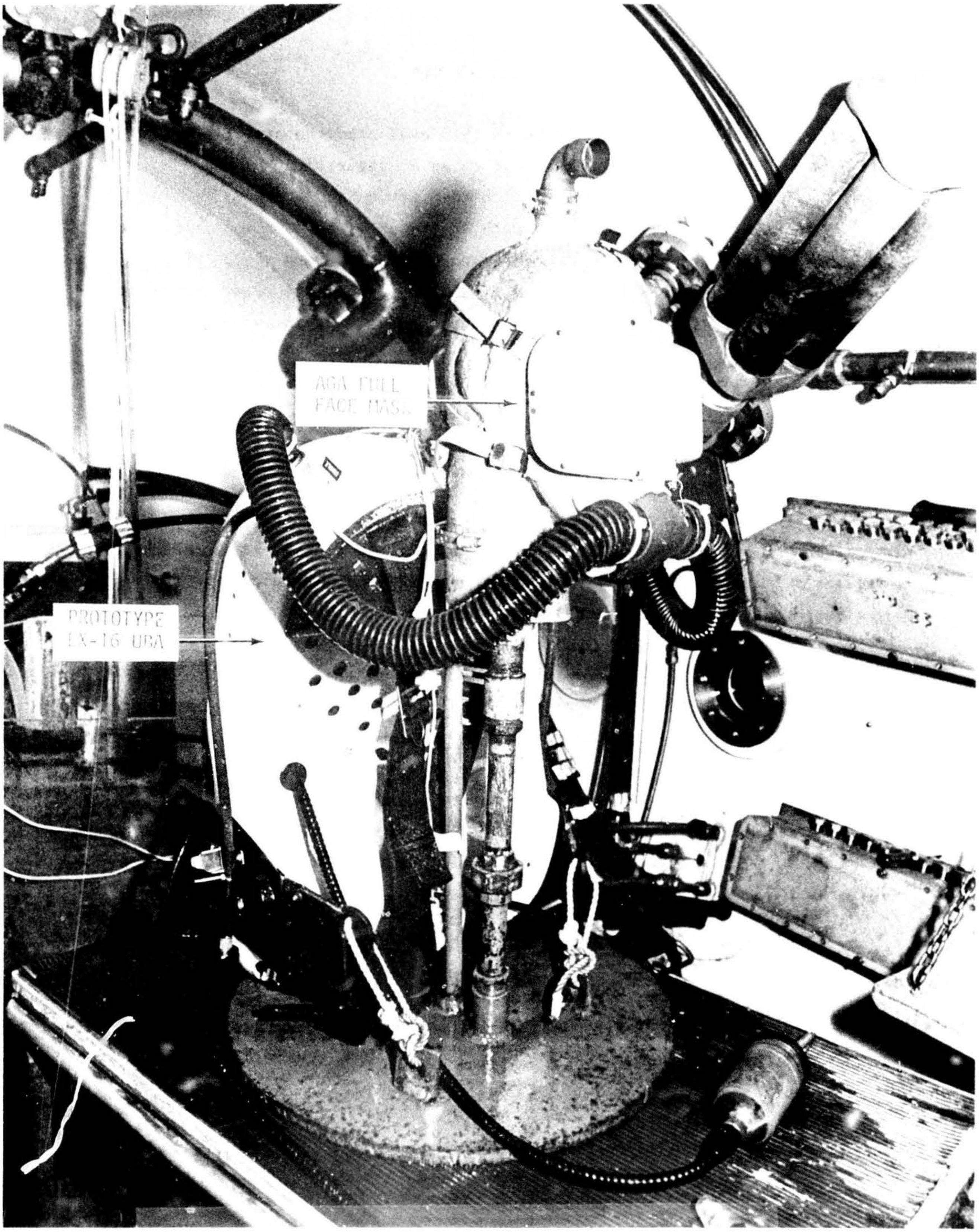


Figure 2. GENERAL TEST SETUP IN EDF CHAMBER

DESCRIPTION OF EX-16 TEST CONFIGURATIONS

A. Breathing Resistance Tests

The EX-16 UBA was tested in three configurations during the breathing resistance test to evaluate the effect on overall breathing effort by different hose, mouthpiece and full face mask combinations. The general test setup for all configurations is shown in figure 2.

1. Base line data were obtained using the EX-16 UBA backpack with the same hose/mouthpiece configuration currently used with the MK-15 Mod 0 UBA. This consisted of the corrugated rubber hoses and the Scott Aviation mouthpiece originally supplied with the MK-15 Mod 0 UBA. This combination was designated the "Standard" or (16-S).

2. The second combination tested consisted of the same Scott mouthpiece but the hoses were a larger-diameter type currently available from AGA Corporation, Sweden. This configuration was designated "Enlarged Breathing Hose" or (16-BH).

3. The third test combination consisted of the enlarged AGA hoses and a new AGA full face mask with a special set of low resistance, non-return valves which are significantly larger and softer than those found in the Scott Aviation mouthpiece. This test setup was designated "AGA Mask-Equipped" or (16-AGA).

B. Canister Duration Tests

All canister duration tests were performed with the EX-16 UBA in the standard (16-S) configuration. The purpose of these tests was to evaluate the canister's ability to remove CO_2 from the diver's exhaled breathing gas at various depths, water temperatures and gas mixes. The tests were conducted in a manner which closely simulates those conditions experienced during actual manned testing at depth in the NEDU Ocean Simulation Facility. The breathing simulator was set up to control diver's CO_2 add rate, exhaled gas relative humidity, diver's exhaled gas temperature, and diver work rates in a manner consistent with actual manned tests.

The test setup for unmanned canister duration tests is illustrated in figure 3.

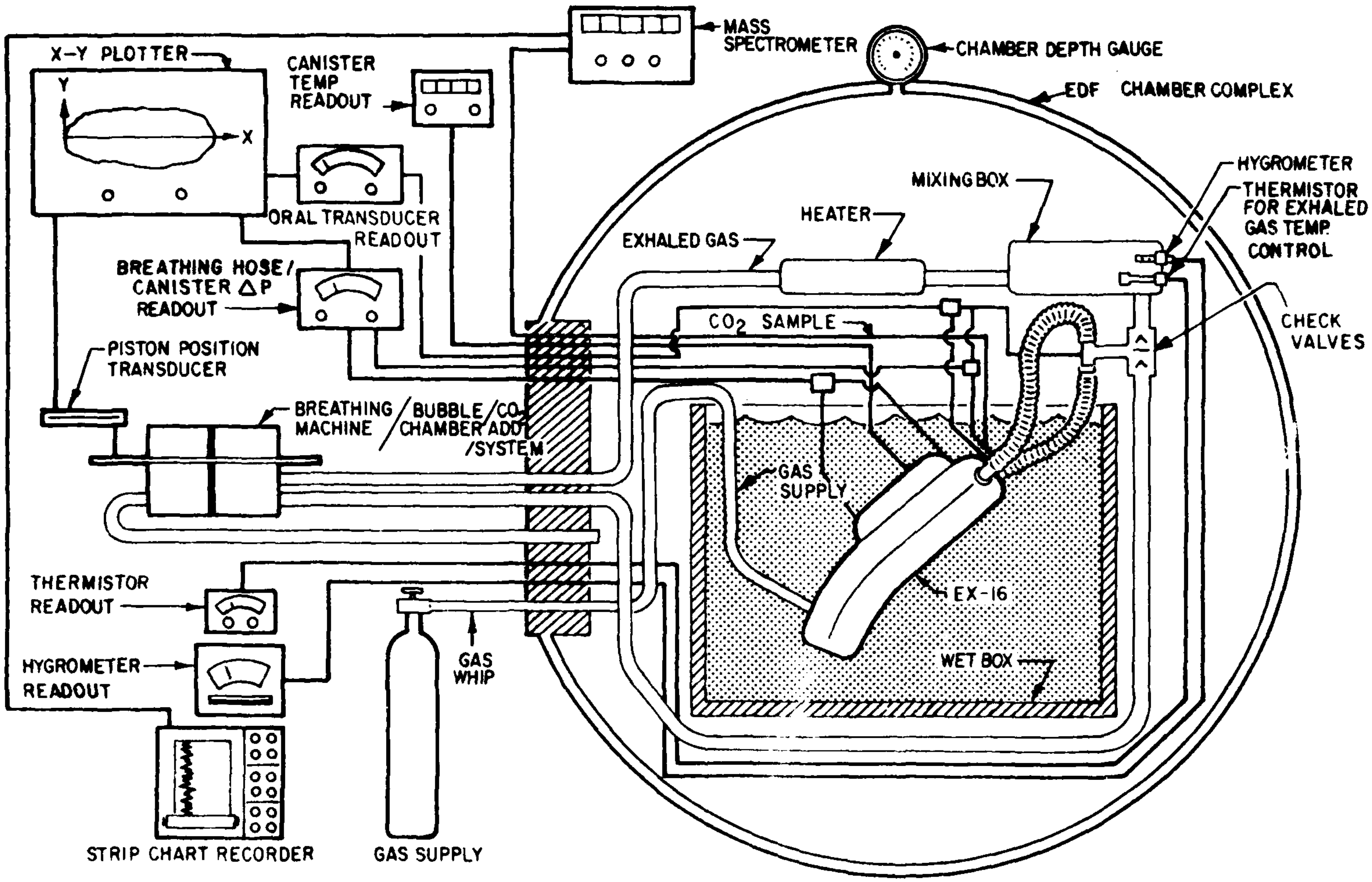


Figure 3. TEST SETUP

TEST PROCEDURE

TEST PLAN

The complete test plan is provided in Appendix A. All applicable NEDU test procedures for unmanned testing were followed. Test equipment is listed in Appendix B and illustrated in figure 3. A breathing machine simulated inhalation and exhalation at various depths and diver work rates.

CONTROLLED PARAMETERS

A. Breathing Resistance Tests

The following parameters were controlled for breathing resistance tests:

1. Diluent: Air and HeO_2 (84% He, 16% O_2)
2. Breathing rate/tidal volume / RMV / Simulated Diver Work Rate

a.	15 BPM/1.5 liters	22.5 RMV	Light
b.	20 BPM/2.0 liters	40.0 RMV	Moderate
c.	25 BPM/2.5 liters	62.5 RMV	Moderately Heavy
d.	30 BPM/2.5 liters	75.0 RMV	Heavy
e.	30 BPM/3.0 liters	90.0 RMV	Extreme

3. Exhalation/inhalation time ratio: 1.00/1.00
4. Breathing waveform: sinusoid
5. Incremental descent stops for breathing resistance tests:
   a. Air - 0 to 150 FSW in 33 FSW increments
   b. HeO_2 - 0 to 300 FSW in 33 FSW increments

B. Canister Duration Tests

Controlled parameters during canister duration tests were as follows:

1. Diluent: Air and HeO_2 (84/16)
2. CO_2 breakthrough tests were conducted using H.P. Sodasorb at water temperatures of 70°F and 35°F (± 2°).
3. CO_2 add rate:
   a. 0.9 LPM at 23.0 RMV (2.0 LTV x 11.5 BPM) during 4-minute rest cycle

b. 2.0 LPM at 50.0 RMV (2.0 LTV x 25 BPM) during 6-minute work cycle

NOTE: The CO_2 add rate is cycled between 0.9 and 2.0 LPM at 4- and 6-minute intervals, respectively, for the duration of the canister tests to simulate a man at rest and work producing an average of 1.56 l/min CO_2.

4. Relative humidity of exhaled gas: 90 percent relative humidity (± 2 percent).

5. Control of exhaled gas temperature followed the formula that expired gas temperature equals 24 + 0.32 times inspired gas temperature (T exp = 24 + 0.32 T in °C). NOTE: "T in" was assumed to be 10°C above ambient water temperature.

6. Depth stops for canister duration tests:

a. Air - 0, 75 and 150 FSW

b. HeO_2 - 300 FSW

MEASURED PARAMETERS

A. Breathing Resistance Tests

1. Inhalation/exhalation peak ΔP (cm H_2O)
2. ΔP across CO_2 absorbent canister (cm H_2O)
3. Inhalation/exhalation breathing hose ΔP (cm H_2O)

B. Canister Duration Tests

1. CO_2 level out of scrubber, expressed as a percentage of S.E. values
2. Canister bed temperatures in °F (canister duration test only)

COMPUTED PARAMETERS

Respiratory work in kg.m/liter tidal volume was computed from ΔP vs. tidal volume plots obtained from breathing resistance tests.

DATA PLOTTED

A. The following data were plotted for breathing resistance test:

1. Inhalation maximum ΔP vs. depth
2. Exhalation maximum ΔP vs. depth

3. Respiratory work vs. depth

4. Canister maximum ΔP vs. depth

5. Exhalation and inhalation hose maximum ΔP vs. depth.

B. The following data were plotted for canister duration tests:

1. CO_2 (% of S.E.) out of scrubber vs. time

2. Canister bed temperature vs. time and percentage of CO_2 out of scrubber.

RESULTS AND DISCUSSION

BREATHING RESISTANCE

Breathing resistance was measured for each of the three EX-16 test configurations (standard hoses with MK-6 mouthpiece, enlarged breathing hoses with MK-6 mouthpiece, enlarged hoses with AGA full face mask) at five RMVs to simulate light through extreme diver work rates. Light work was measured at 22.5 RMV, moderate work at 40.0 RMV, moderately heavy work at 62.5 RMV, heavy work at 75.0 RMV and extreme work at 90.0 RMV. These tests indicate the full range of EX-16 UBA performance.

Breathing resistances plotted with air used as the breathing medium are given in figures 4 through 8. Data represents maximum values measured from the no-flow condition during one complete inhalation/exhalation cycle at a given depth and RMV. Figures 9 through 13 plot breathing resistances for the three EX-16 configurations when HeO_2 was used as the breathing gas. Note that breathing resistance data was only taken on the enlarged breathing hoses and AGA configurations at 40.0, 75.0 and 90.0 RMV.

EXHALATION CHARACTERISTICS

At 40.0 RMV (figure 5) on air, exhalation resistance for the AGA mask-equipped rig (16-AGA) remained below 15.0 cm of H_2O, while the standard (16-S) and enlarged breathing hose (16-BH) version rose above 20 cm H_2O. Both standard and 16-BH configurations saw exhalation resistance rise to the 50 cm H_2O range at 75.0 RMV, while the 16-AGA remained under 30 cm H_2O (figure 7). Similar results were obtained at 90.0 RMV (figure 8) when exhalation resistance remained below 40 cm H_2O for the 16-AGA at maximum depth, but rose significantly for the 16-S and 16-BH configurations.

The same general trend was noted at all depths and RMVs on HeO_2 (figures 9 through 13) although peak pressures were less due to the decreased density of HeO_2.

INHALATION CHARACTERISTICS

Inhalation resistance encountered by the three EX-16 test rigs followed a pattern similar to that experienced with exhalation resistance. Inhalation

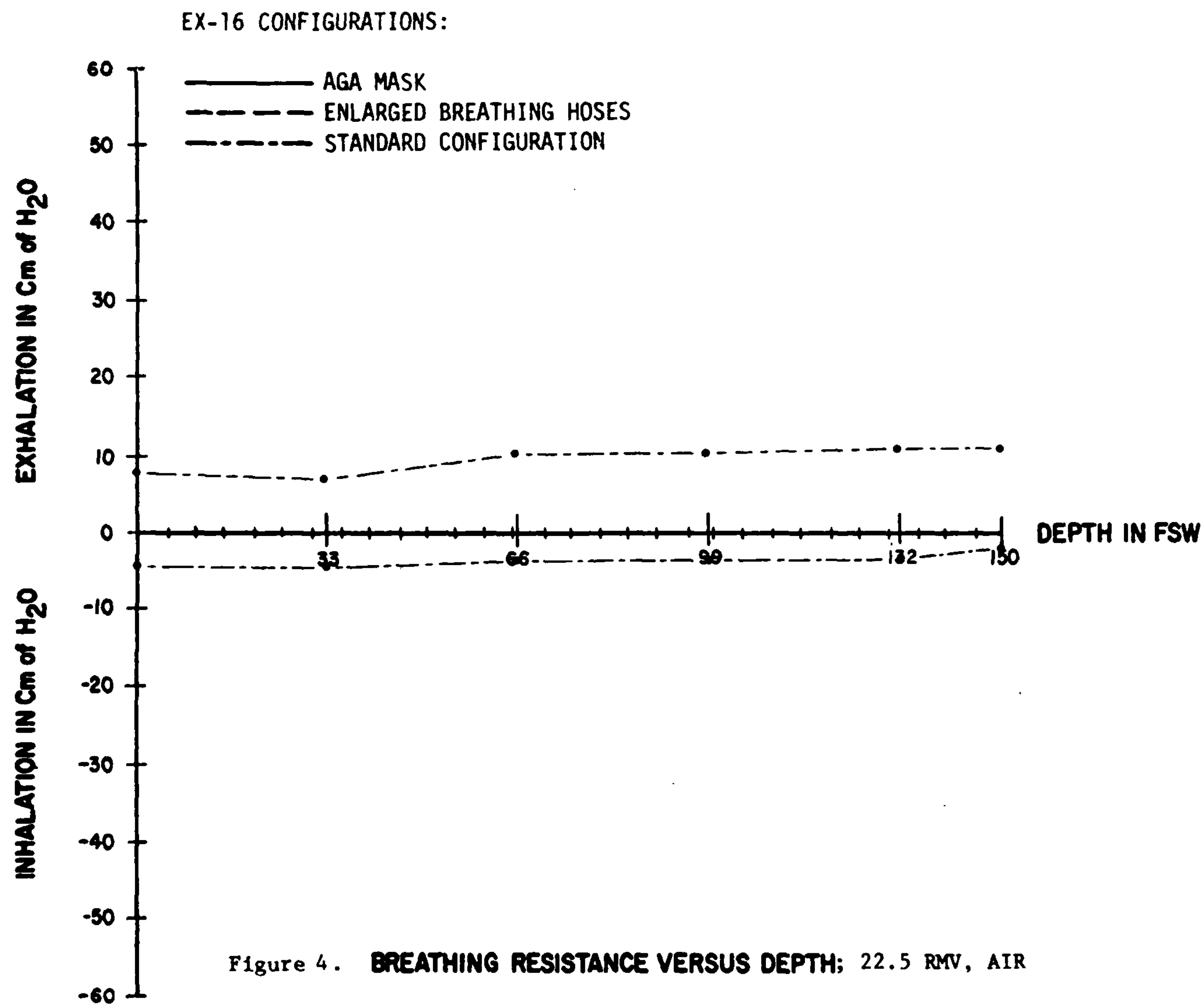


Figure 4. **BREATHING RESISTANCE VERSUS DEPTH;** 22.5 RMV, AIR

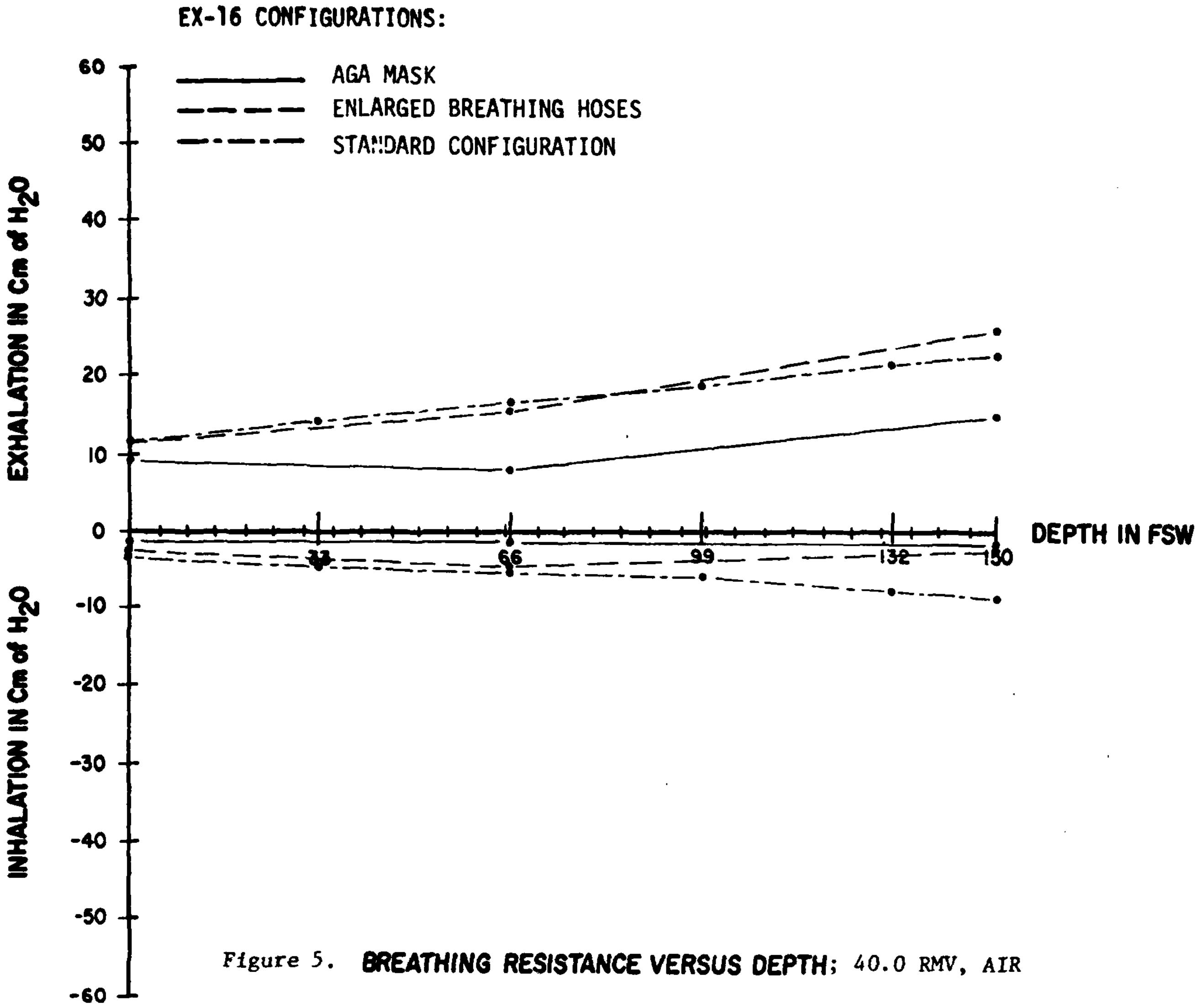


Figure 5. **BREATHING RESISTANCE VERSUS DEPTH**; 40.0 RMV, AIR

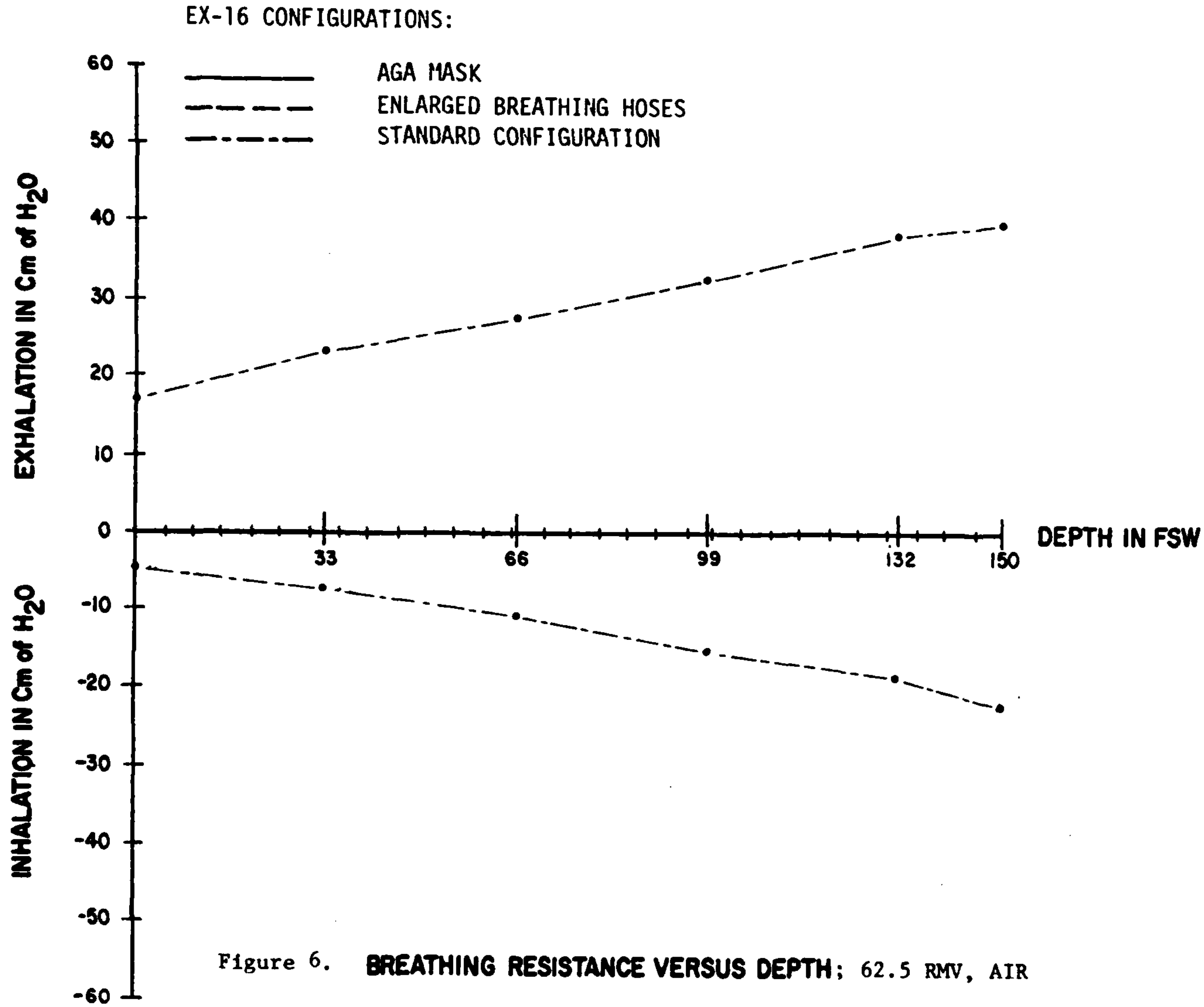


Figure 6. **BREATHING RESISTANCE VERSUS DEPTH**; 62.5 RMV, AIR

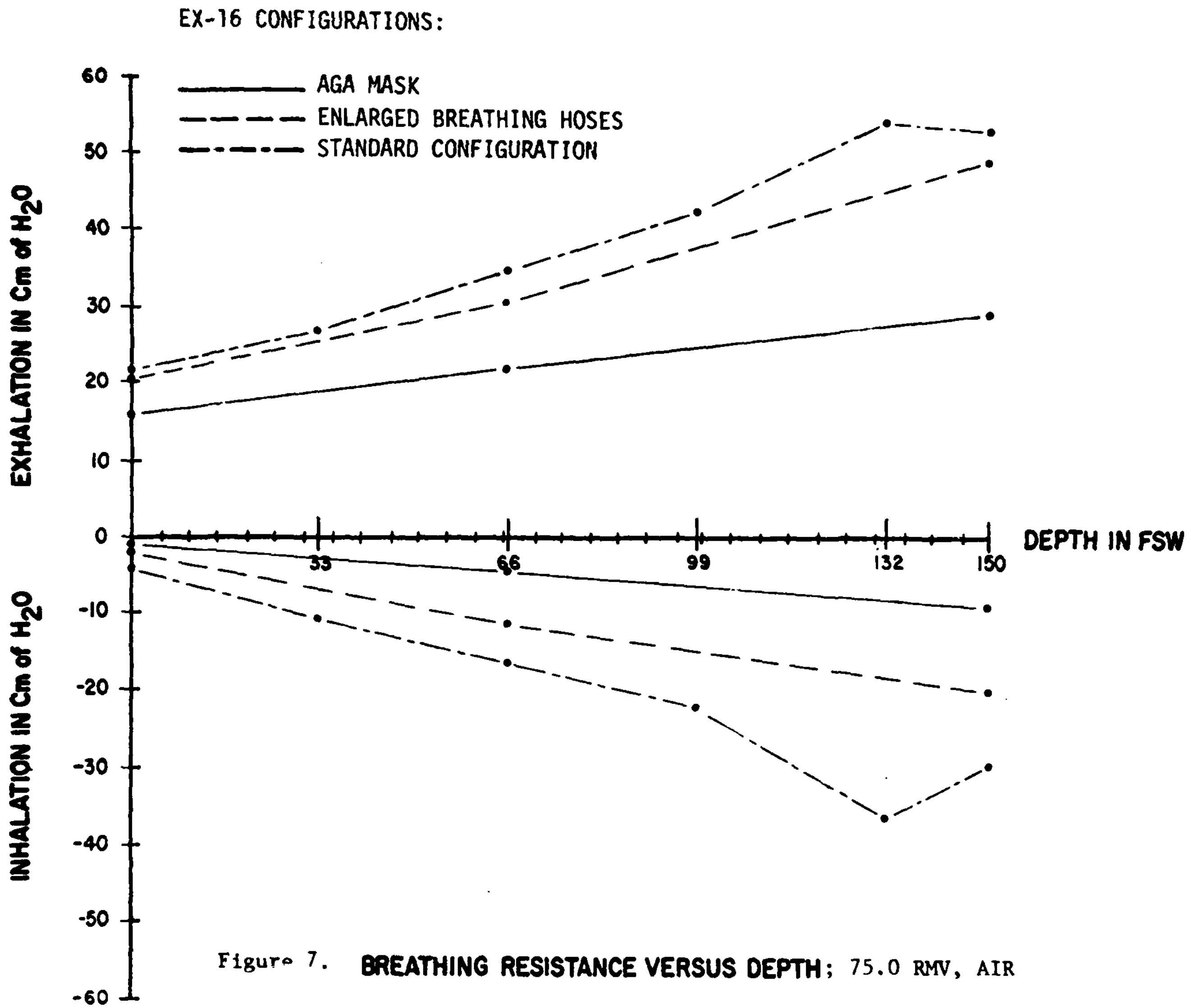


Figure 7. **BREATHING RESISTANCE VERSUS DEPTH**; 75.0 RMV, AIR

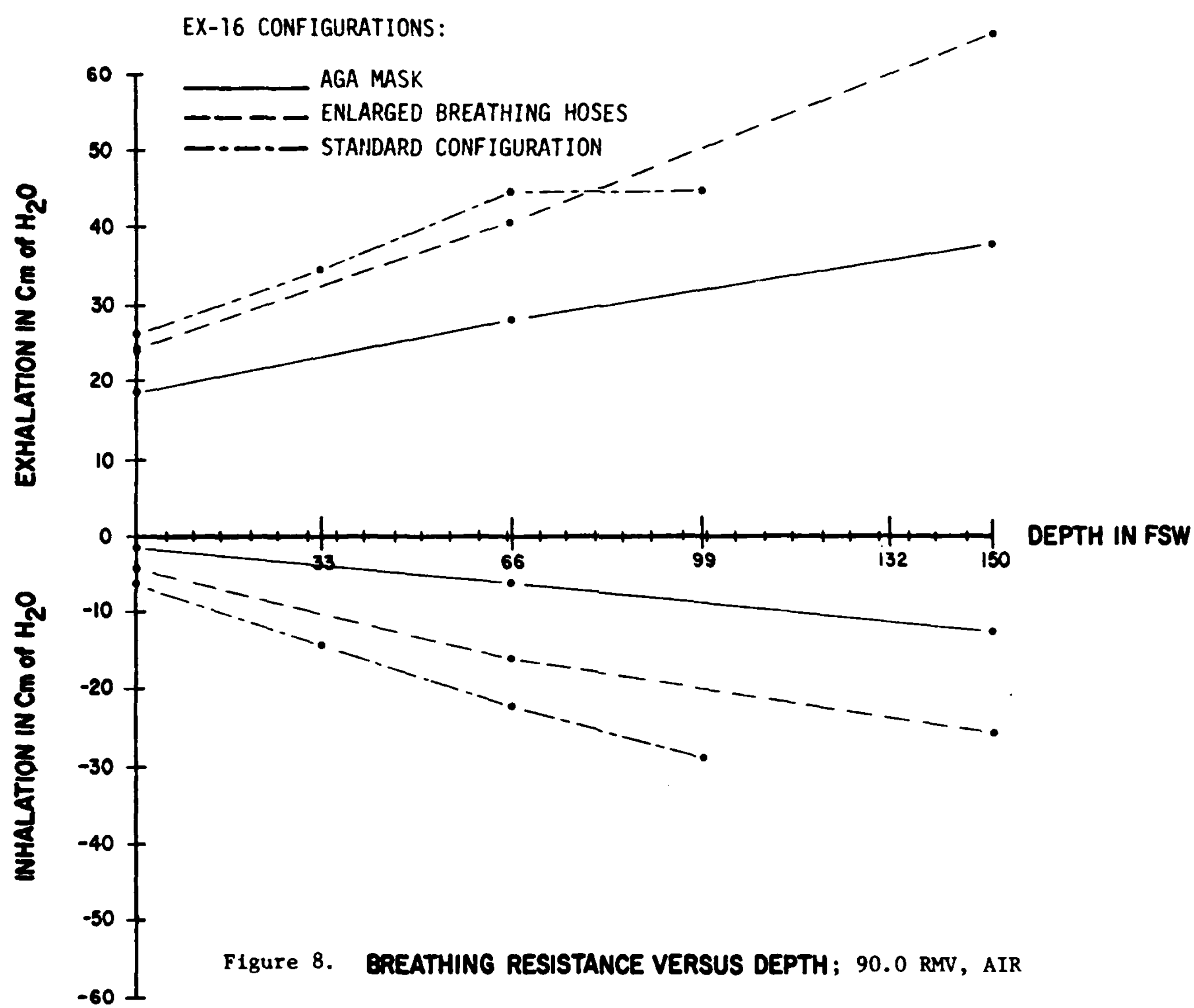


Figure 8. **BREATHING RESISTANCE VERSUS DEPTH**; 90.0 RMV, AIR

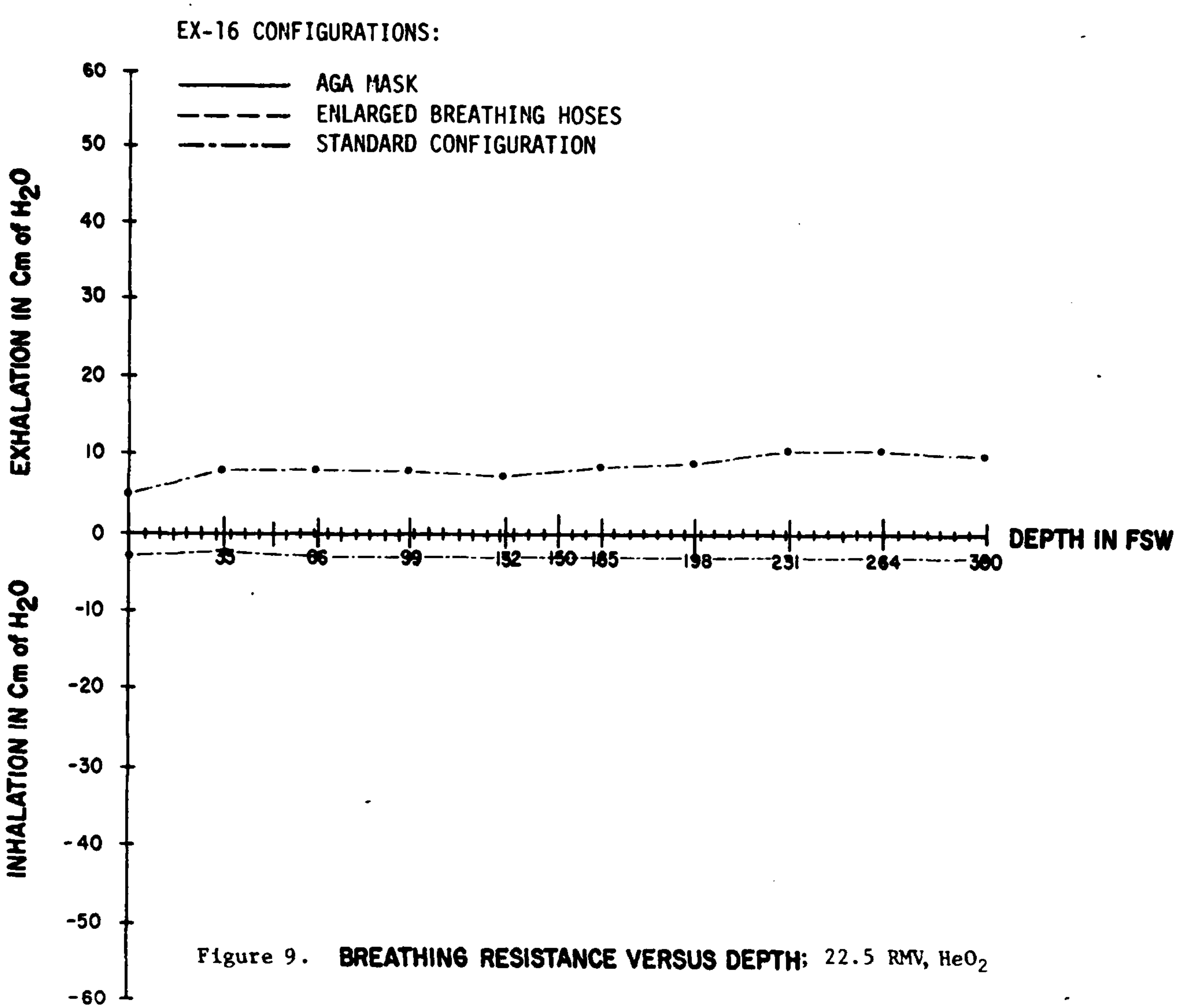


Figure 9. **BREATHING RESISTANCE VERSUS DEPTH:** 22.5 RMV, HeO_2

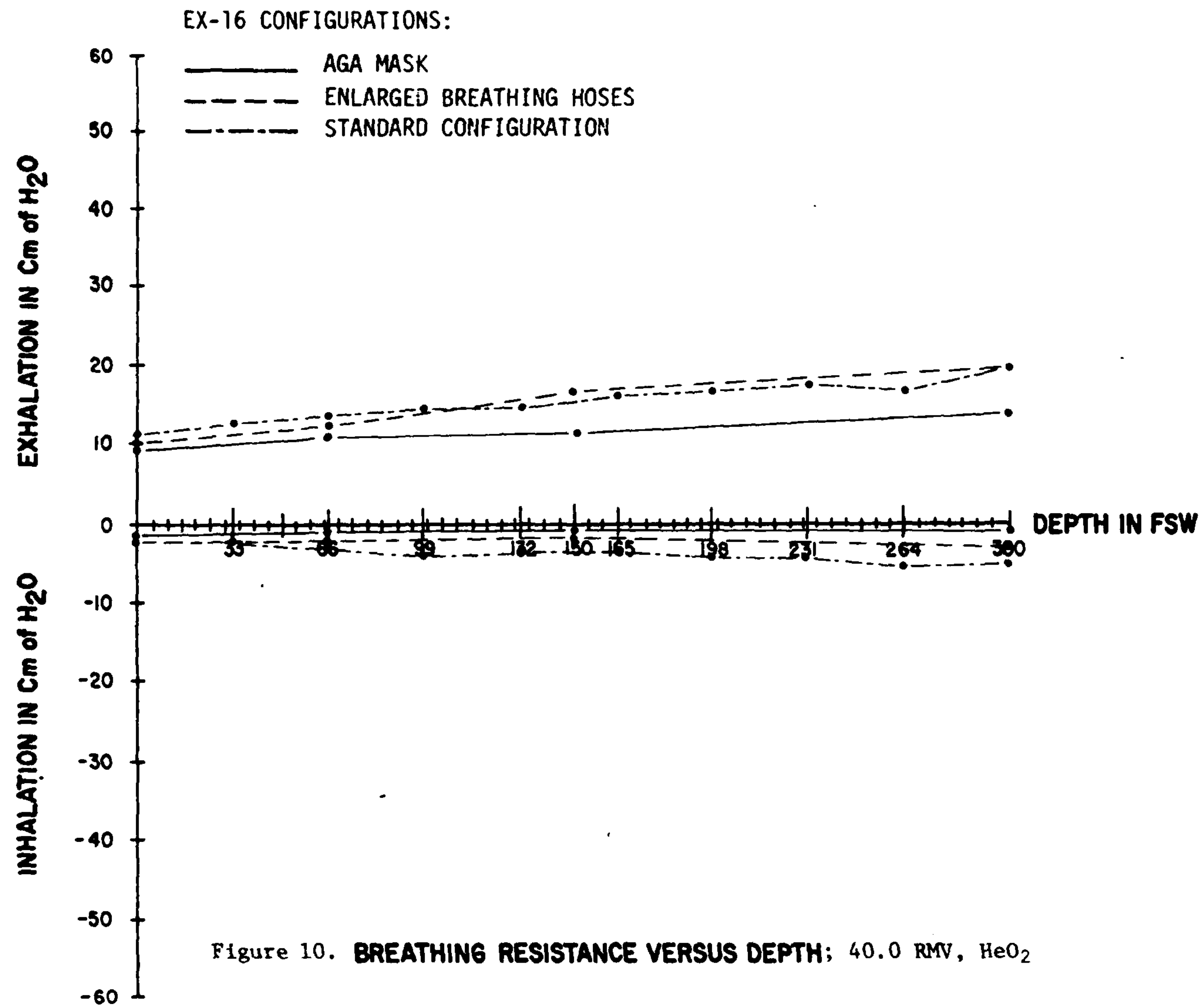


Figure 10. **BREATHING RESISTANCE VERSUS DEPTH**; 40.0 RMV, HeO_2

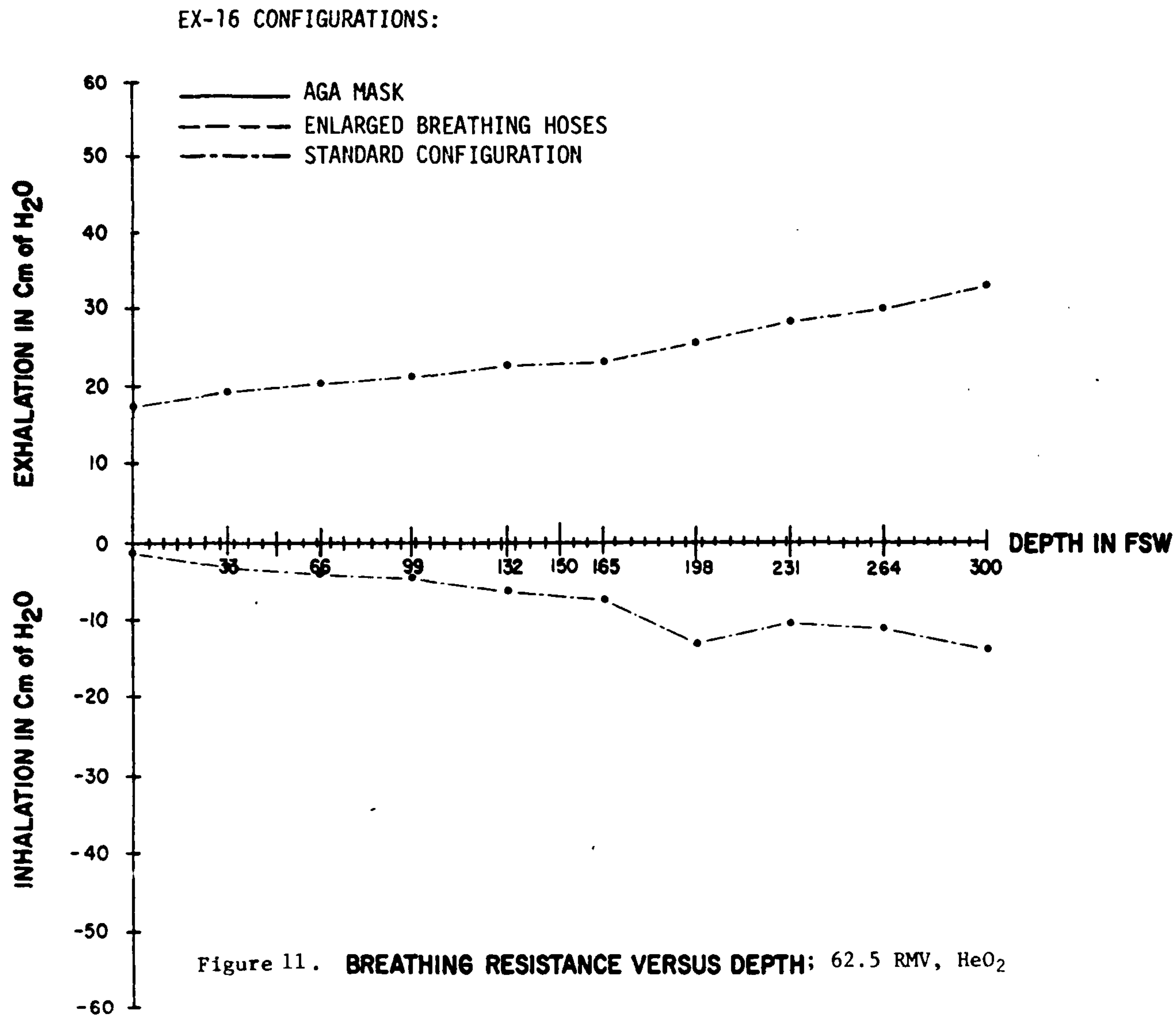


Figure 11. **BREATHING RESISTANCE VERSUS DEPTH**; 62.5 RMV, HeO_2

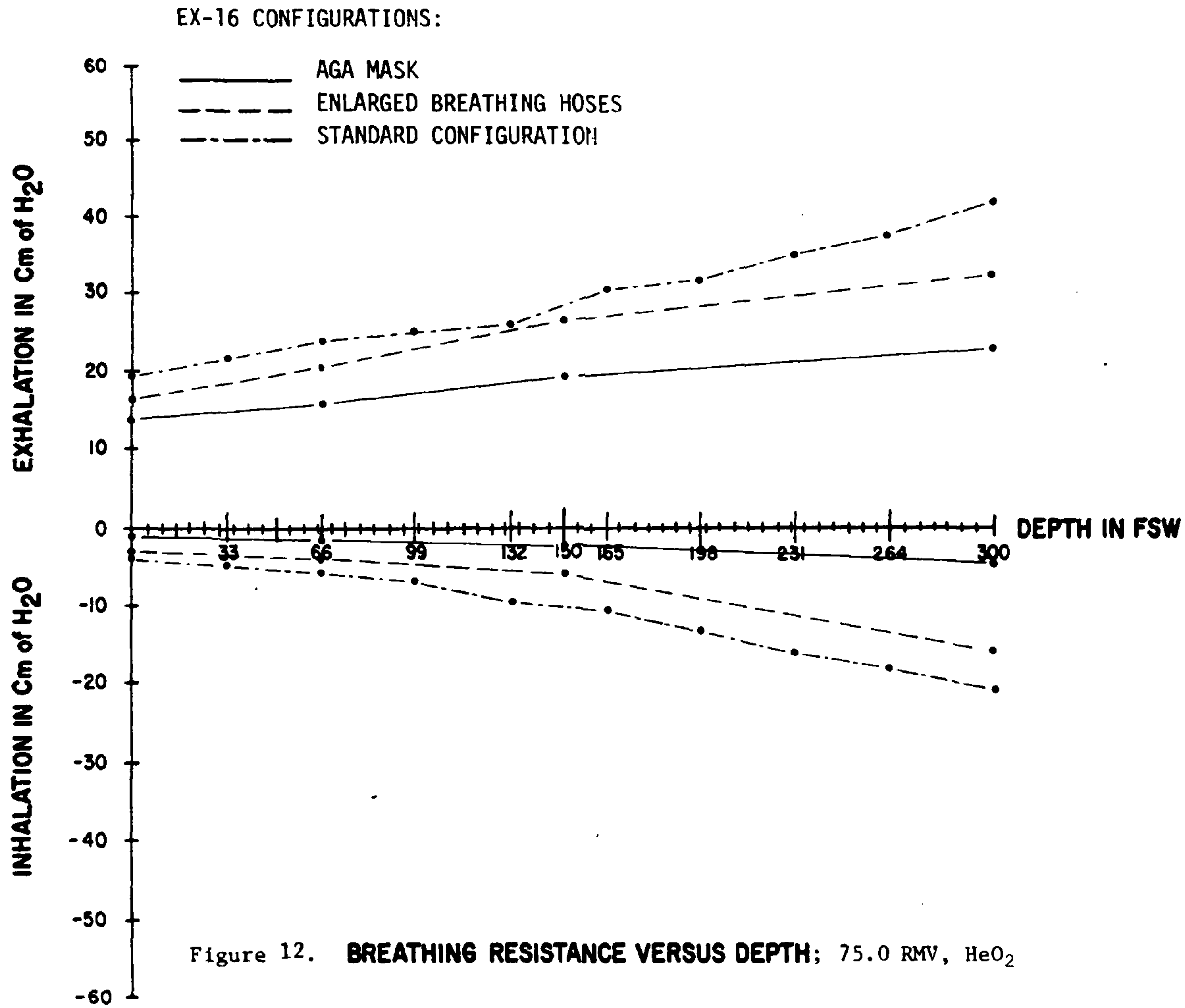


Figure 12. **BREATHING RESISTANCE VERSUS DEPTH**; 75.0 RMV, HeO_2

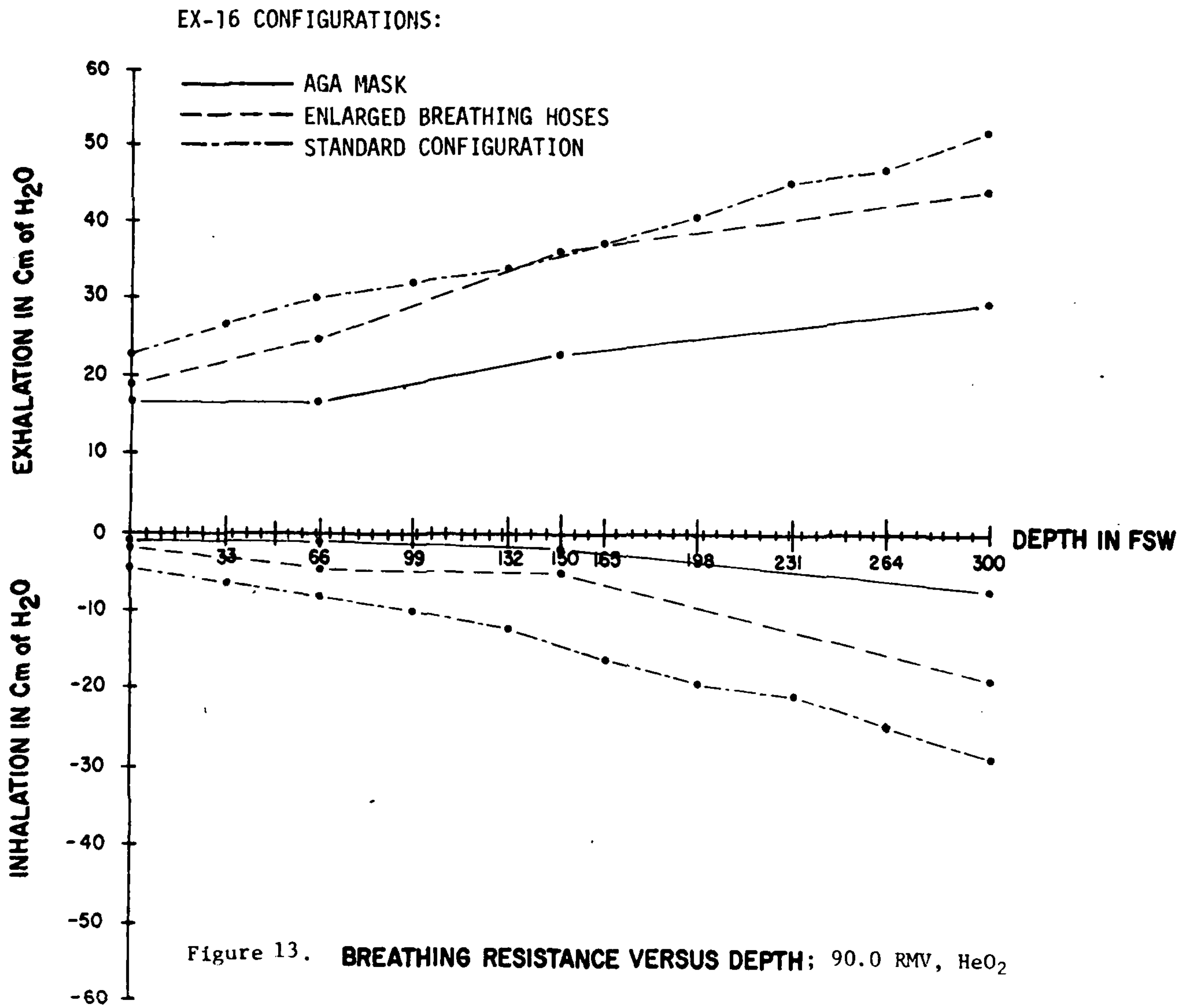


Figure 13. **BREATHING RESISTANCE VERSUS DEPTH**; 90.0 RMV, HeO_2

resistance was minimal through 40.0 RMV on air, but increased substantially at higher RMVs for the 16-S and 16-BH, while the 16-AGA only reached 12.5 cm H_2O at 90.0 RMV in 150 FSW. Once again, inhalation resistance was generally lower in all three configurations on HeO_2. The same trends were observed with respect to the performance of each mode as experienced on air (figures 9 through 13).

BREATHING RESISTANCE ATTRIBUTABLE TO CO_2 CANISTER AND BREATHING HOSES

In an effort to discern modification and design opportunities, the EX-16 test effort included measurement of differential pressures for the CO_2 canister and breathing hoses. A pressure transducer was located between the mouthpiece and canister hose fittings on the exhalation side to measure hose/check valve ΔP. Pressure losses in the exhalation and inhalation hoses were equal under the same test conditions. For measuring canister pressure drop on exhalation, a pressure transducer was located between the inhalation and exhalation hose fittings on the canister. Specific results are discussed below and portrayed graphically in figures 14 through 21.

CO_2 Canister ΔP

Canister ΔP represents a portion of the total exhalation breathing resistance and, as could be expected, canister differential pressure rose in proportion to the RMV and depth encountered by all three EX-16 test configurations. Figures 14 and 15 plot canister ΔP for the standard MK-6 mouthpiece configuration on both air and HeO_2. Canister ΔP remained almost constant regardless of depth or breathing mix at each RMV level and was not an excessive contributing factor to overall breathing resistance in any test configuration.

Breathing Hose ΔP

Measurement of differential pressure of the breathing hoses (figures 16 through 21) reestablished the trend noted during total breathing resistance evaluation; that is, the 16-AGA showed the lowest ΔP throughout, while the 16-BH and standard EX-16 obtained proportionately higher differential pressures. At 90.0 RMV on air (figure 18), the 16-S exceeded 30.0 cm H_2O at 99 FSW, while the 16-BH did not reach that peak until exposed to 150 FSW. At the same depth and RMV, the 16-AGA encountered only 9.2 cm H_2O. It should be noted that hose

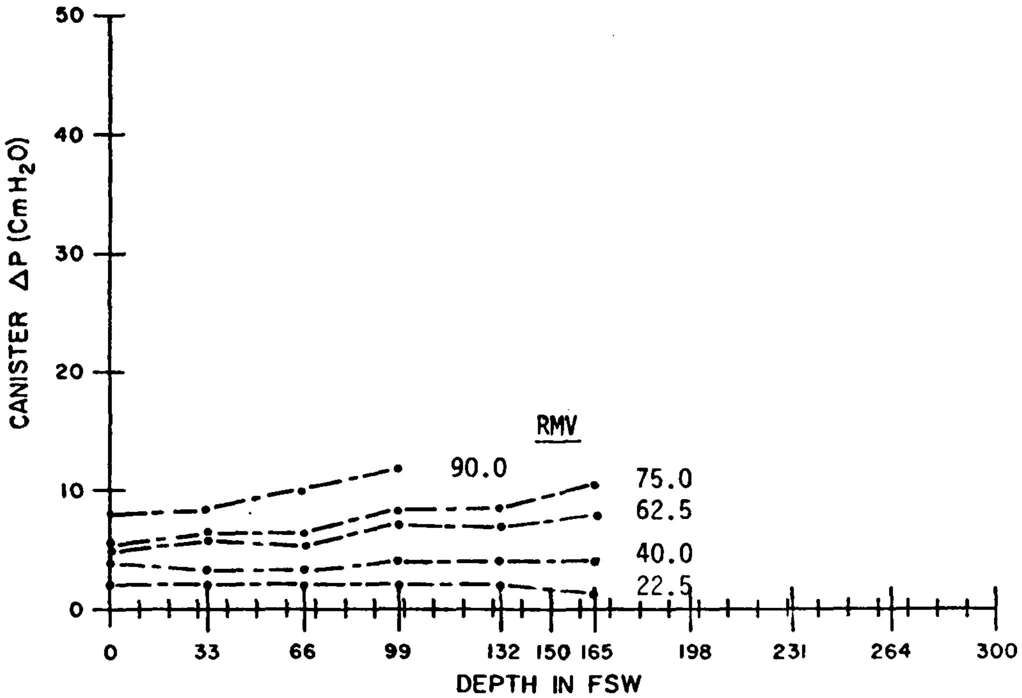


Figure 14. CANISTER ΔP; AIR

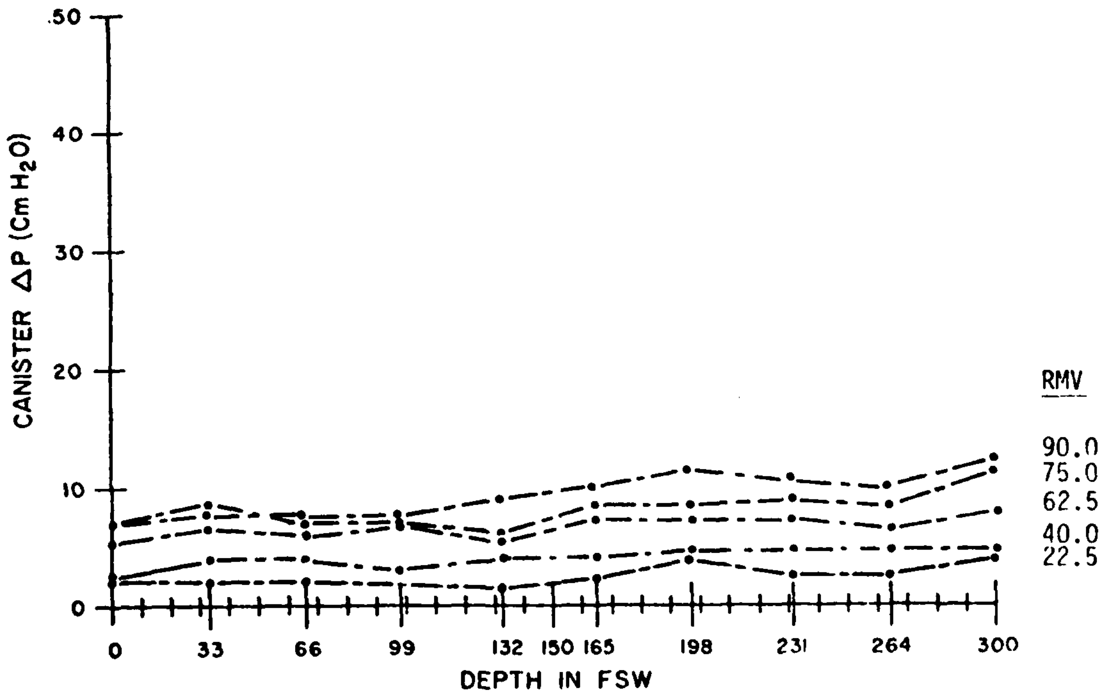


Figure 15. CANISTER ΔP; HeO_2

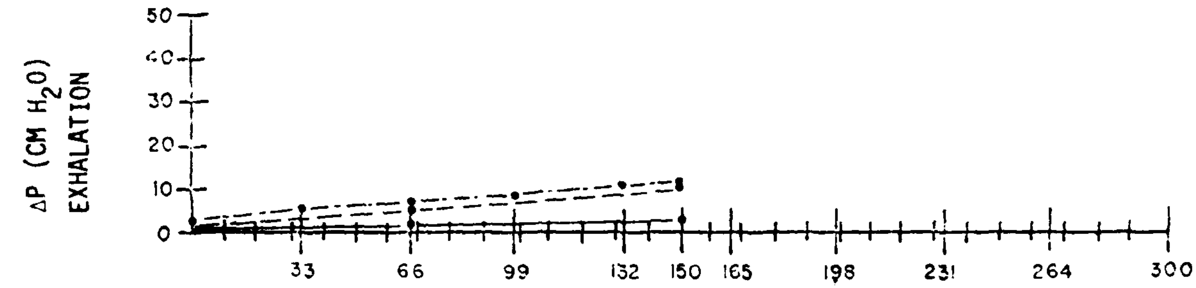


Figure 16. HOSE ΔP VERSUS DEPTH; 40.0 RMV, AIR

EX-16 CONFIGURATIONS

AGA MASK
ENLARGED BREATHING HOSES
STANDARD CONFIGURATION

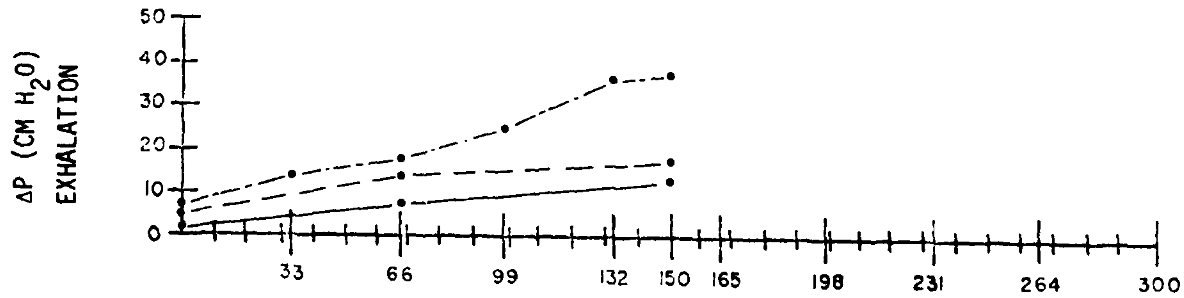


Figure 17. HOSE ΔP VERSUS DEPTH; 75.0 RMV, AIR

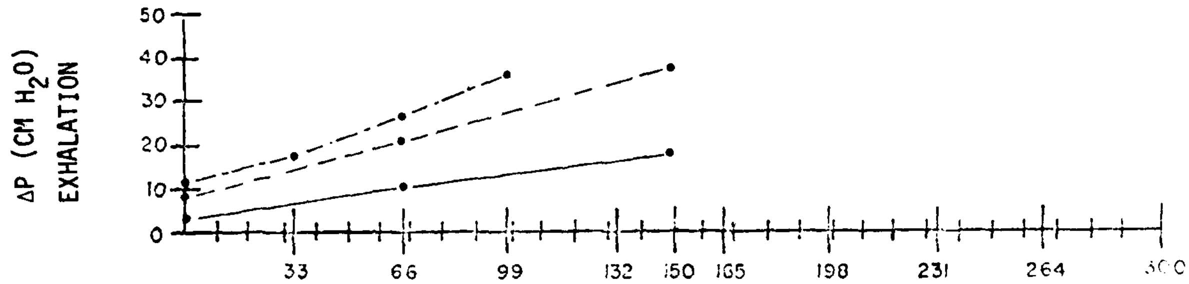


Figure 18. HOSE ΔP VERSUS DEPTH; 90.0 RMV, AIR

EX-16 CONFIGURATIONS

AGA MASK

ENLARGED BREATHING HOSES

STANDARD CONFIGURATION

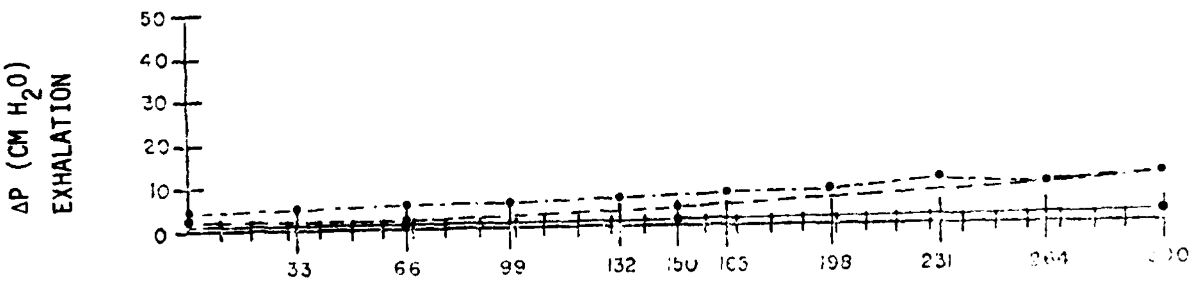


Figure 19. HOSE ΔP VERSUS DEPTH; 40.0 RMV, HeO_2

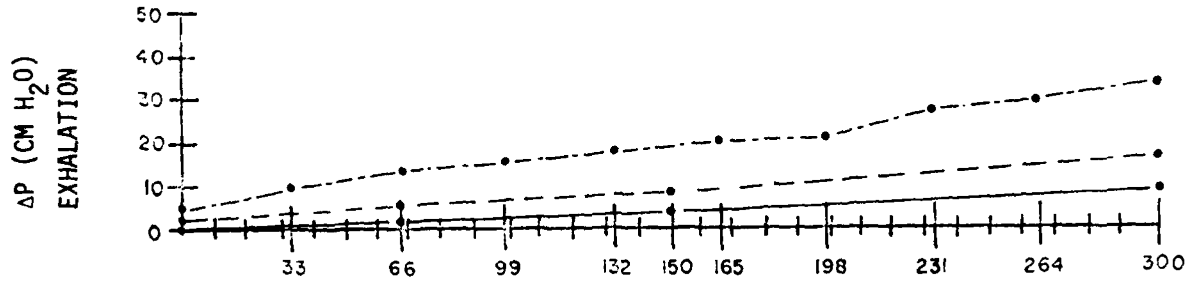


Figure 20. HOSE ΔP VERSUS DEPTH; 75.0 RMV, HeO_2

EX-16 CONFIGURATIONS

——————— AGA MASK

– – – – – – – ENLARGED BREATHING HOSES

– · – · – · – STANDARD CONFIGURATION

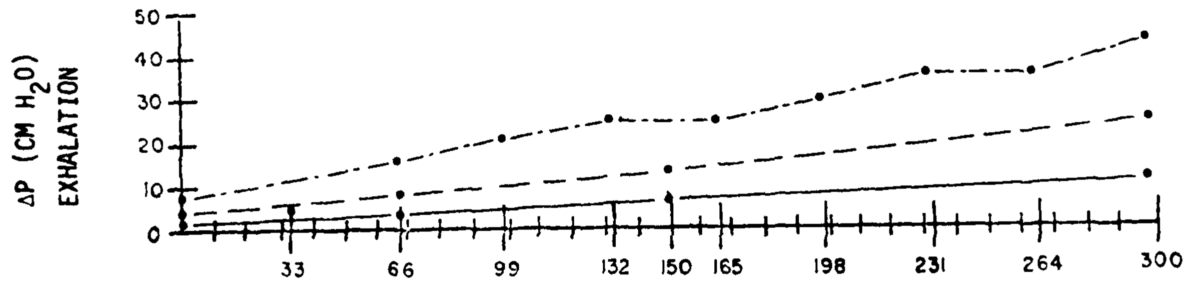


Figure 21. HOSE ΔP VERSUS DEPTH; 90.0 RMV, HeO_2

ΔP includes the MK-6 mouthpiece and AGA mask check valve ΔP. The same general trend was noted during the mixed gas tests (figures 19 through 21).

RESPIRATORY WORK

The specification governing testing of open circuit breathing apparatus cites peak inhalation and peak exhalation pressures as the standard for evaluation (reference 1). However, measurements of diver's external respiration work in operating his breathing apparatus yield useful data for evaluating equipment performance. Breathing work in the range of 0.10 to 0.20 kg.m/l is considered to be reasonable. The significance of these values has not been fully tested. However, they do represent reasonable work levels in state-of-the-art UBAs and are included here for comparison purposes. (Breathing work is defined as the area enclosed by a typical pressure-volume loop generated during one complete breathing cycle divided by the tidal volume.)

Breathing work required for the Standard EX-16 on air (figure 22) stays below 0.10 through 150 FSW at 22.5 RMV and 40.0 RMV. At greater RMVs, breathing work increases rapidly and approaches 0.60 kg.m/l at a depth of 99 FSW and 90.0 RMV.

Attachment of larger breathing hoses (16-BH) results in improved performance at 40.0 RMV to a depth of 150 FSW on air (figure 23), but rapidly peaks to excessive levels at 75.0 and 90.0 RMV.

Lowest breathing work is associated with the AGA full face mask (figure 24) configured test rig. While still high in terms of work of breathing (0.38 kg.m/l at 90.0 RMV) on air, this configuration showed an improvement of nearly 40 percent over the standard and modified breathing hose version of the EX-16 and the MK-15 Mod 0. Values for the three test modes using HeO_2 mix are illustrated in figures 25 through 27. Breathing work with the less dense HeO_2 mix is significantly lower but the improvement in overall respiratory work when comparing the AGA versus the standard configuration is still significant.

CANISTER BREAKTHROUGH/DURATION TEST RESULTS

A total of 10 canister duration studies were conducted in connection with the EX-16 UBA evaluation. Two of these were run for comparison purposes and

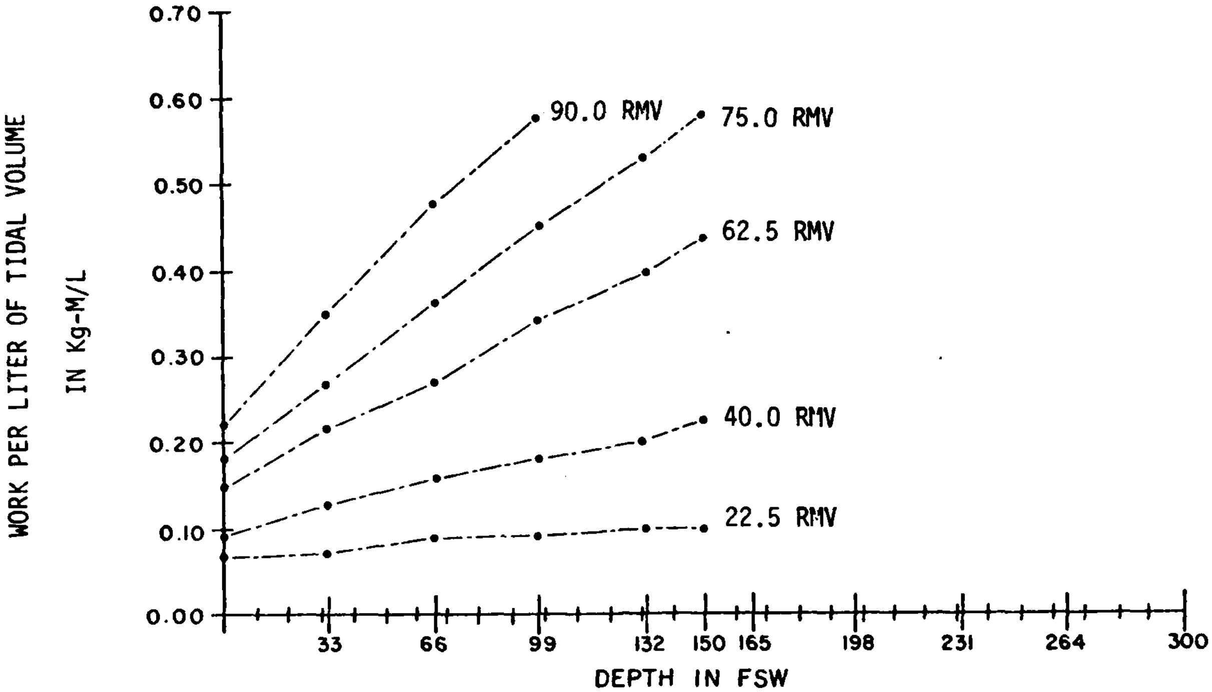


Figure 22. BREATHING WORK VS. DEPTH; STANDARD EX-16 CONFIGURATION; AIR

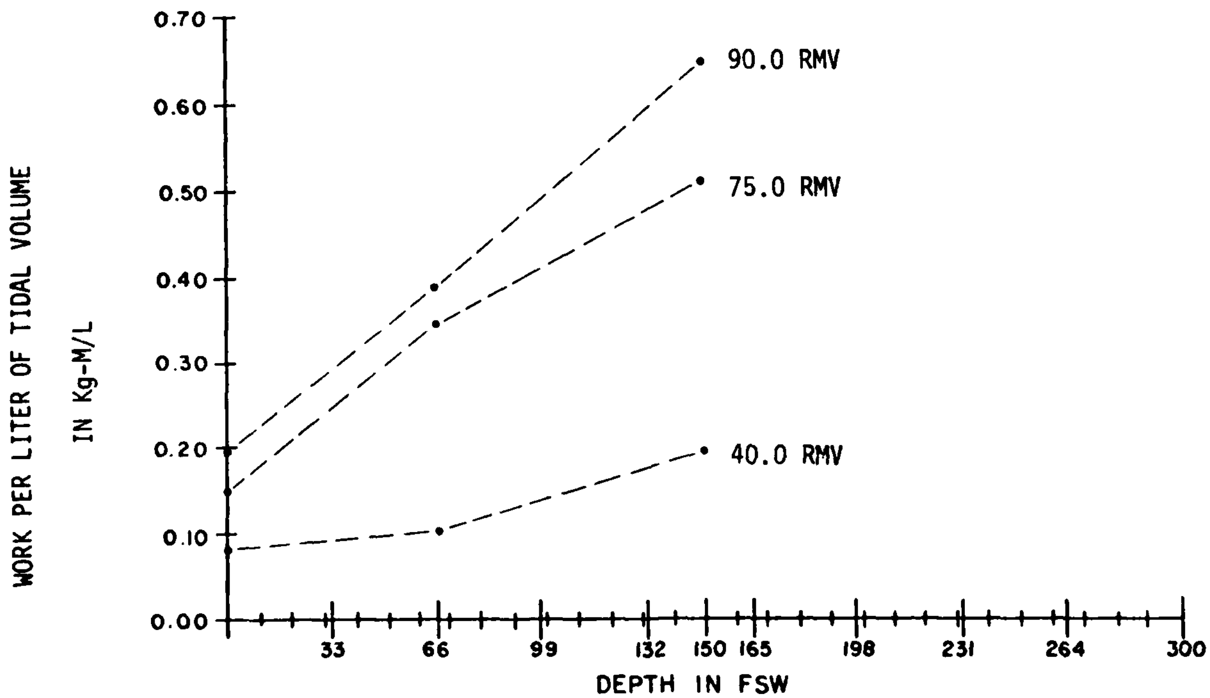


Figure 23. BREATHING WORK VS. DEPTH; EX-16 WITH ENLARGED BREATHING HOSES; AIR

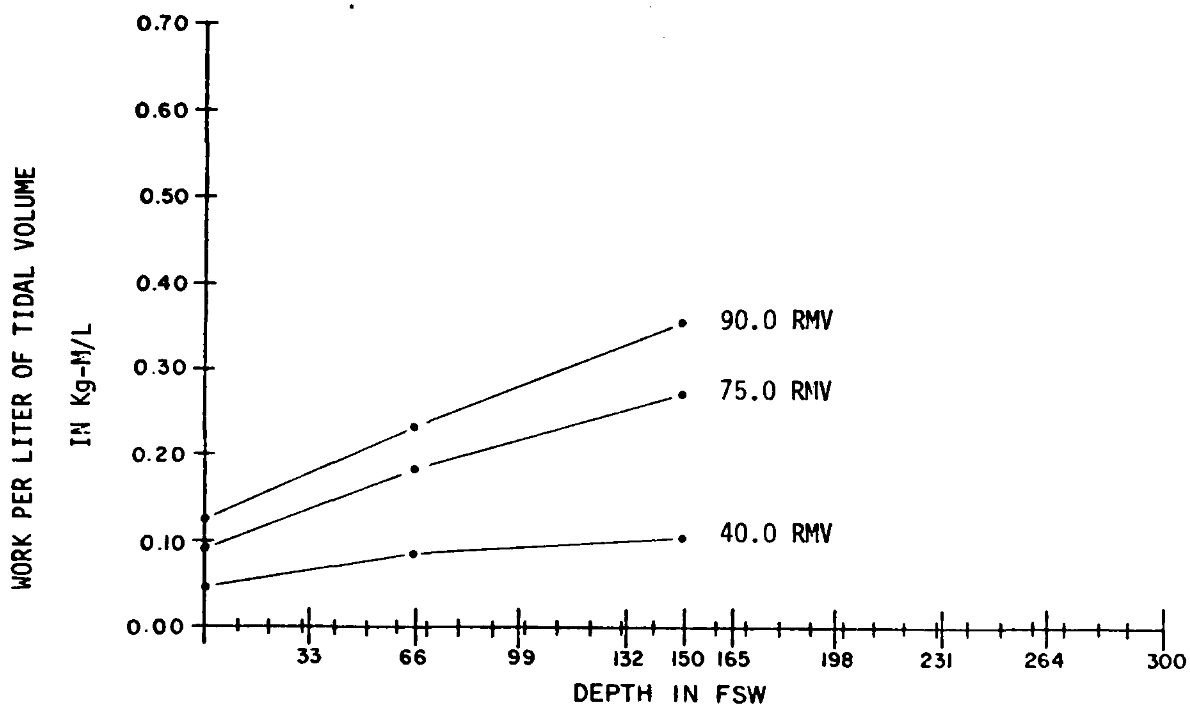


Figure 24. BREATHING WORK VS. DEPTH; EX-16 WITH AGA MASK; AIR

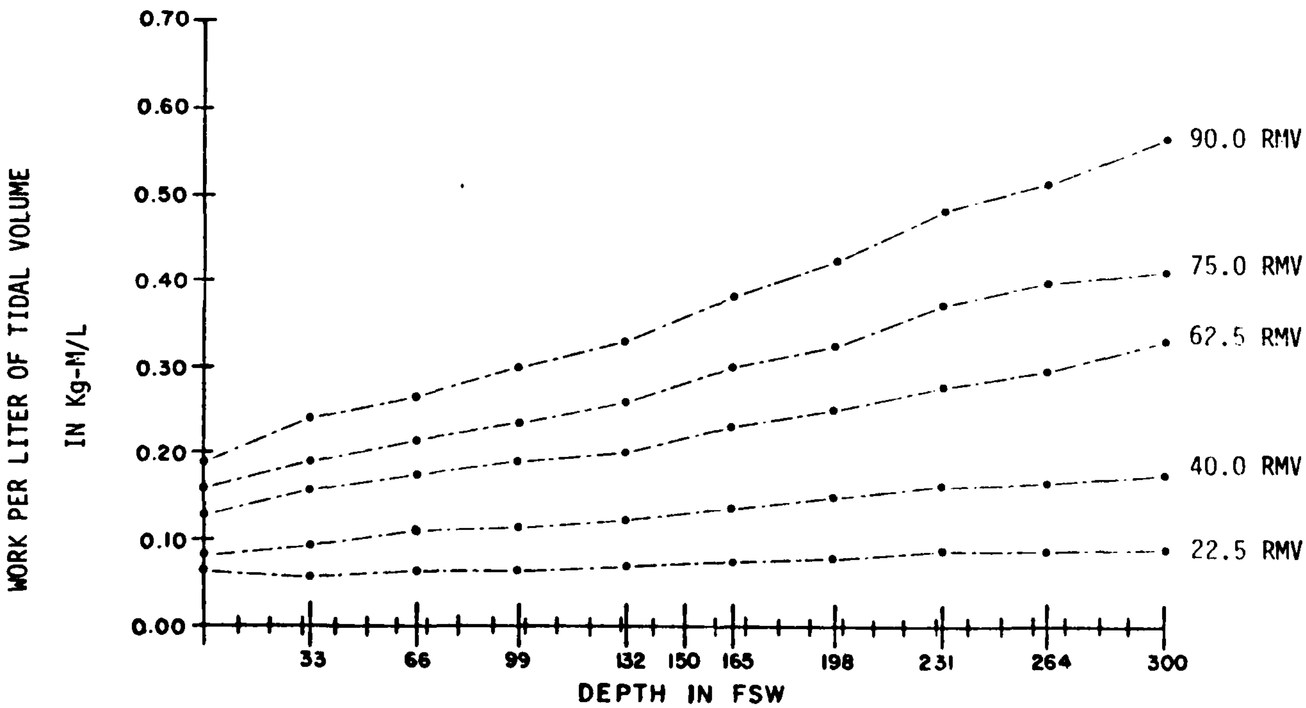


Figure 25. BREATHING WORK VS. DEPTH; STANDARD EX-16 CONFIGURATION; HeO_2

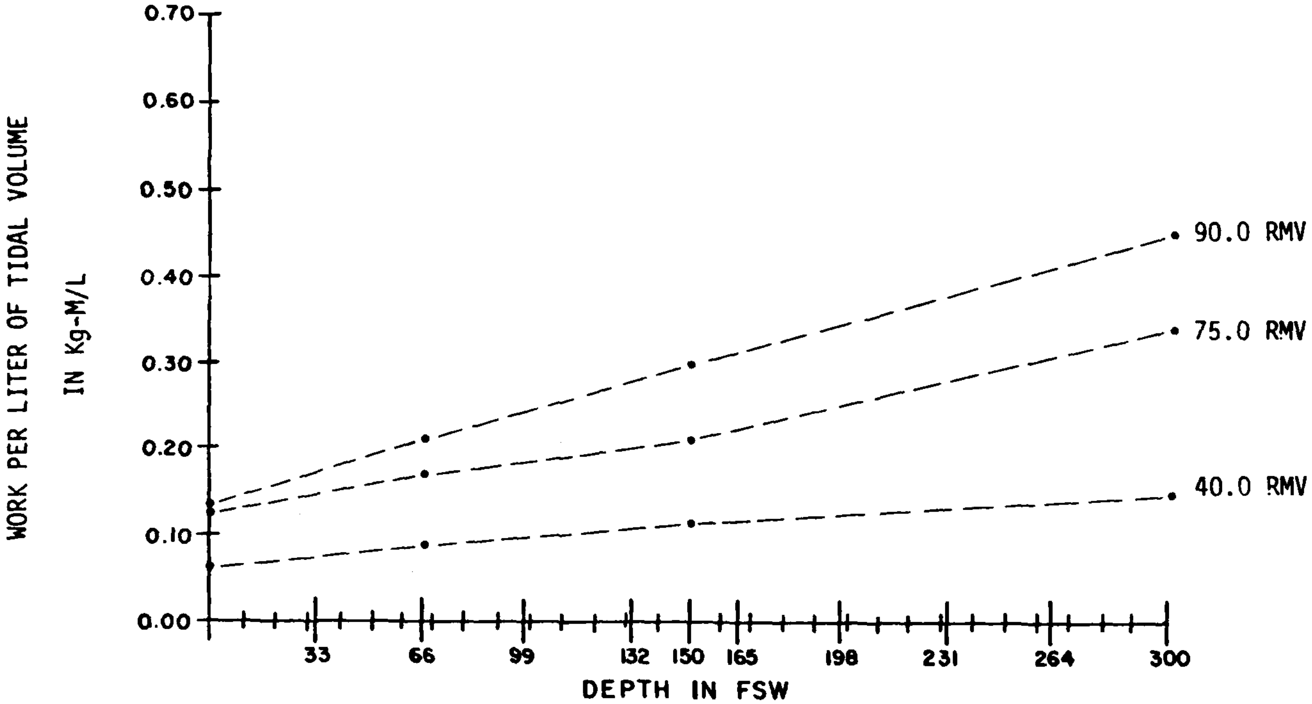


Figure 26. BREATHING WORK VS. DEPTH; EX-16 WITH ENLARGED BREATHING HOSES; HeO_2

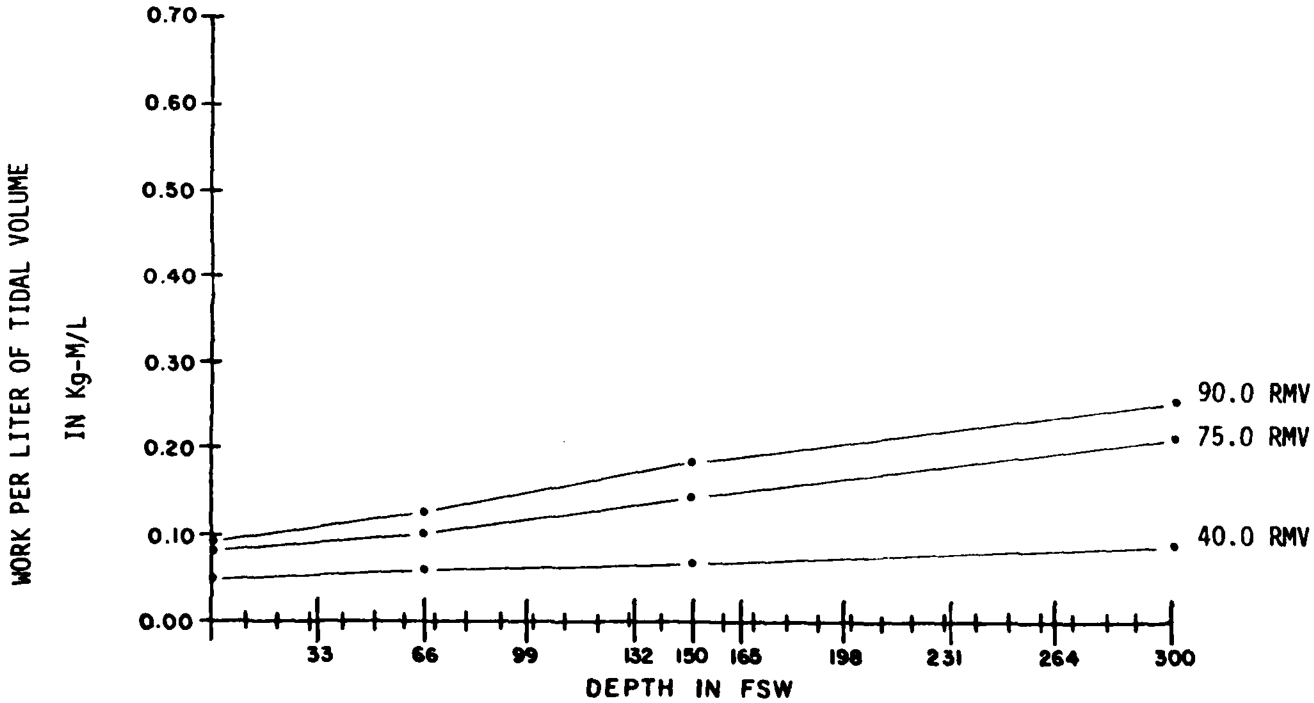


Figure 27. BREATHING WORK VS. DEPTH; EX-16 WITH AGA MASK; HeO_2

utilized a MK-15 Mod 0 apparatus. Canister endurance, depth, breathing gas and water temperatures for this test series are summarized in Table 1, below: NOTE: A total of two tests were run at each set of test parameters.

Table 1. Canister Breakthrough/Endurance

Test No.	UBA Type	Breathing Gas	Water Temp.	Depth (FSW)	Mean Time (min) to 1% S.E.	0.5% S.E.
1	EX-16	Air	70°F	0	296	256
2	EX-16	Air	70°F	75	300	256
3	EX-16	Air	70°F	150	287	238
4	EX-16	Air	35°F	0	298	255
5	EX-16	Air	35°F	75	246	176
6	EX-16	Air	35°F	150	156	90
7	EX-16	HeO_2	35°F	300	150	100
8	EX-16	HeO_2	70°F	300	286	240
9	MK-15	Air	70°F	0	285	240
10	MK-15	Air	70°F	150	228	185

Data yielded very consistent results at constant test parameters. However, in earlier tests it was observed that this canister is quite sensitive to how the absorbent is packed. Consequently, great care was taken to assure uniformity of canister packing procedures in order to achieve consistent results.

Canister Bed Temperatures

Figures 28 through 35 depict temperatures at selected locations within the canister bed for each canister breakthrough test listed in Table 1. Plotted at 30-minute intervals throughout the canister's endurance to breakthrough at 1.0% of CO_2 S.E., these graphs are accompanied by descriptive data relating to the conditions and canister bed utilization.

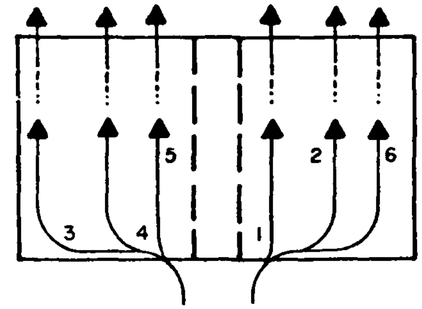
The canister bed temperature progression is plotted for each EX-16 canister test conducted. The pattern of temperature rise and fall at the different locations in the canister bed provide a useful means of determining which parts of the bed are most efficiently used (i.e., the higher the temperature, the more effectively the bed is used). Consistently high temperatures at inner and outer walls and in midbed indicate that channeling is not a problem and

CONDITIONS	
Breathing Gas	AIR
H_2O Temperature	70°F
Exh.Gas Temperature	89°F
Exh.Gas Rel. Humidity	90%
Depth	0 FSW
Absorbent Weight	7.32 lb

CANISTER BED DESCRIPTION

The top one inch of the bed was unused with only slight evidence of channeling around the inner and outer edges. Light moisture accumulated in the bottom of the bed from an unknown leak source. The bed was used uniformly but, judging by the granular color, only 80% of the canister content was utilized when compared to previous surface runs. This is probably due to the amount of indicator in the H.P. Sodasorb rather than an actual change in bed usage.

Location of Temperature Probes (T) in Canister Bed



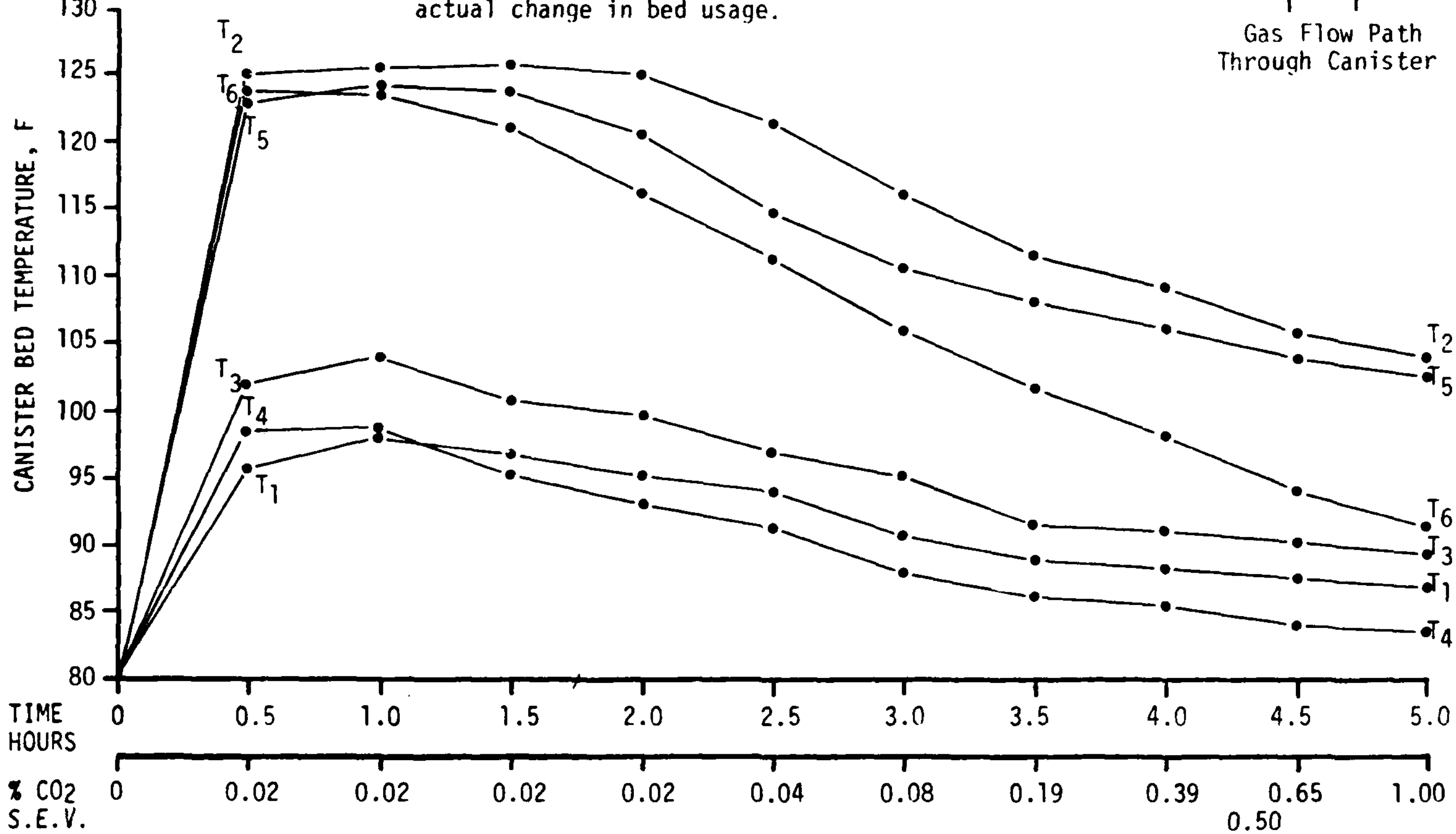


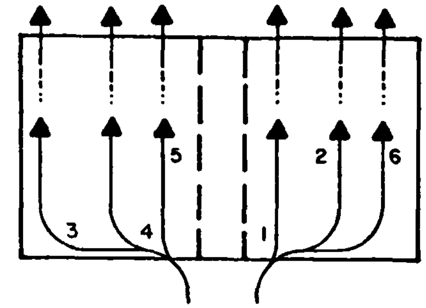
Figure 28. CANISTER BED TEMPERATURES, TEST #1

CONDITIONS	
Breathing Gas	AIR
H_2O Temperature	70°F
Exh.Gas Temperature	89°F
Exh.Gas Rel. Humidity	90%
Depth	75 FSW
Absorbent Weight	6.57 lb

CANISTER BED DESCRIPTION

The bed was very well and uniformly used except for the top 1-1/4-inch layer of H.P. Sodasorb. NOTE: Tests 1, 2 and 3 all used H.P. Sodasorb from the same container. There was a slightly wet area in the bottom of the canister due to a leak in the seal around the outside of the canister. Slight channeling still exists around the inside and outside edges of the canister.

Location of Temperature Probes (T) in Canister Bed



Gas Flow Path Through Canister

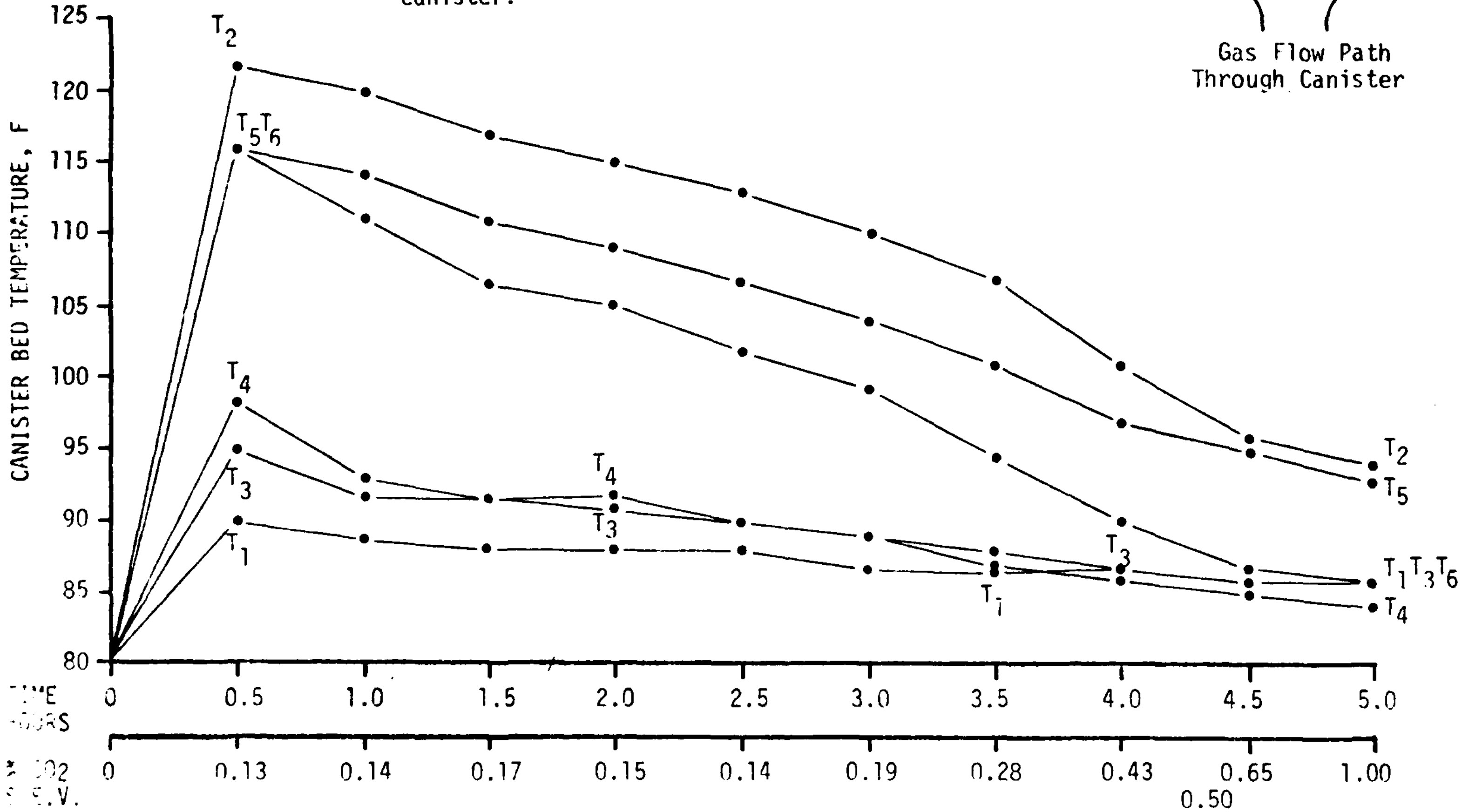


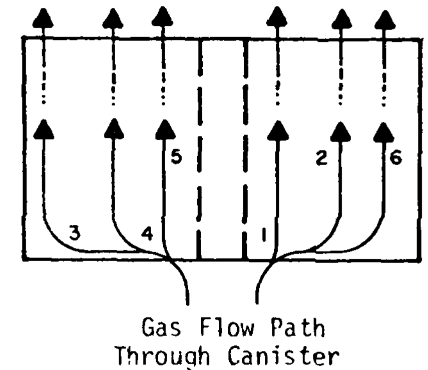
Figure 29. CANISTER BED TEMPERATURES, TEST #2

CONDITIONS		
Breathing Gas		AIR
H_2O Temperature		70°F
Exh.Gas	Temperature	89°F
	Rel. Humidity	90%
Depth		150 FSW
Absorbent Weight		7.17 lb

CANISTER BED DESCRIPTION

Slight evidence of channeling around inner and outer edges at canister top. Top 1-inch layer of absorbent granules shows no indication of use. Main body of bed uniformly used.

Location of Temperature Probes (T) in Canister Bed



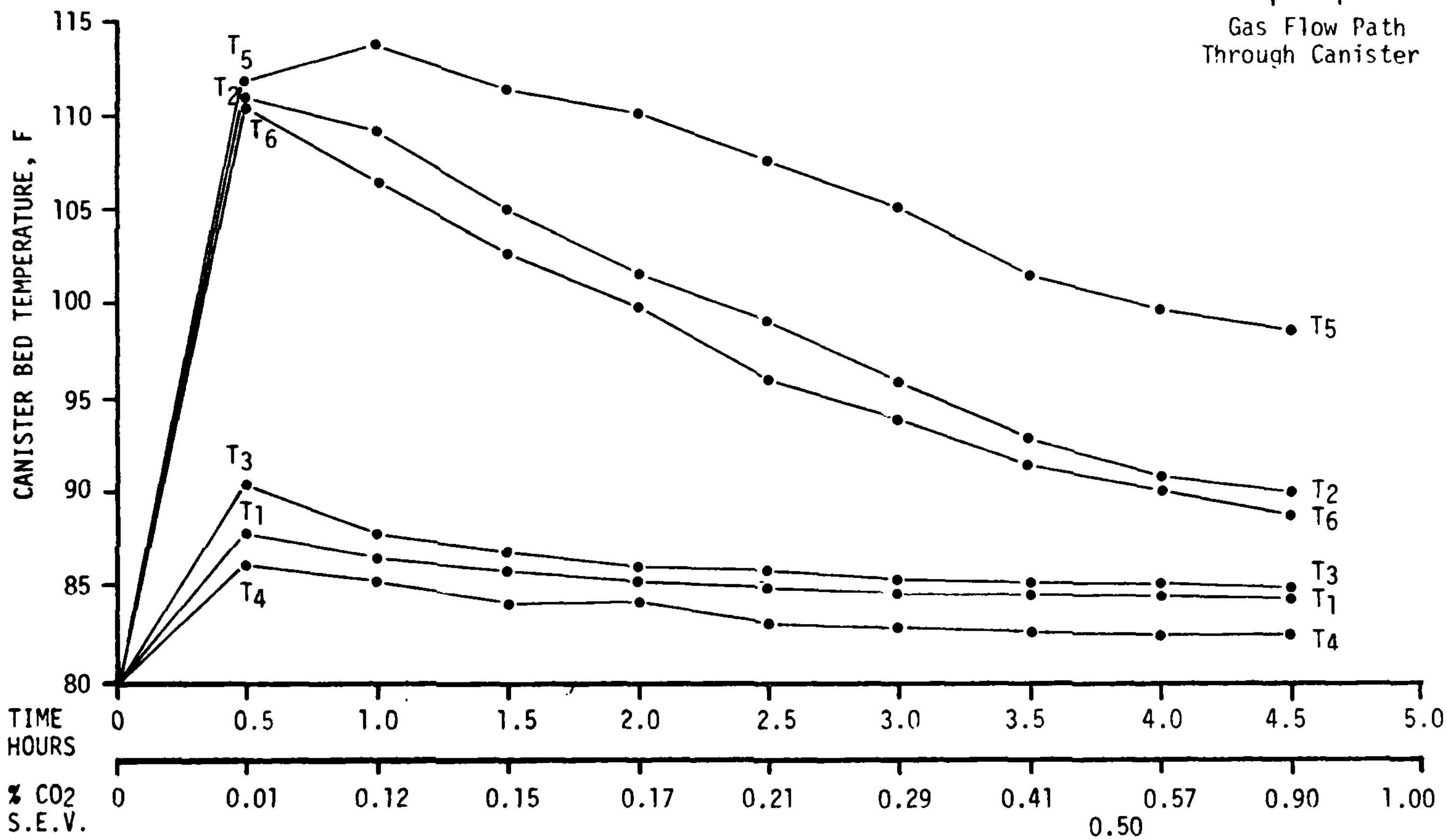
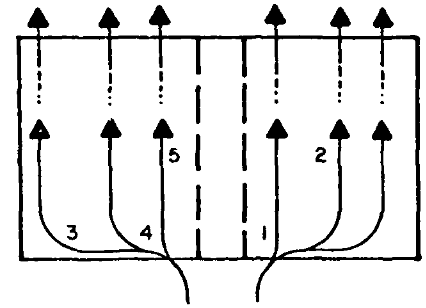


Figure 30. CANISTER BED TEMPERATURES, TEST #3

CONDITIONS	
Breathing Gas	AIR
H_2O Temperature	35°F
Exh.Gas Temperature	82°F
Exh.Gas Rel. Humidity	90%
Depth	0
Absorbent Weight	7.32 lb

CANISTER BED DESCRIPTION

Canister bed shows the same use as in Test 1; top 1-inch layer unused and only slight evidence of channeling at top.



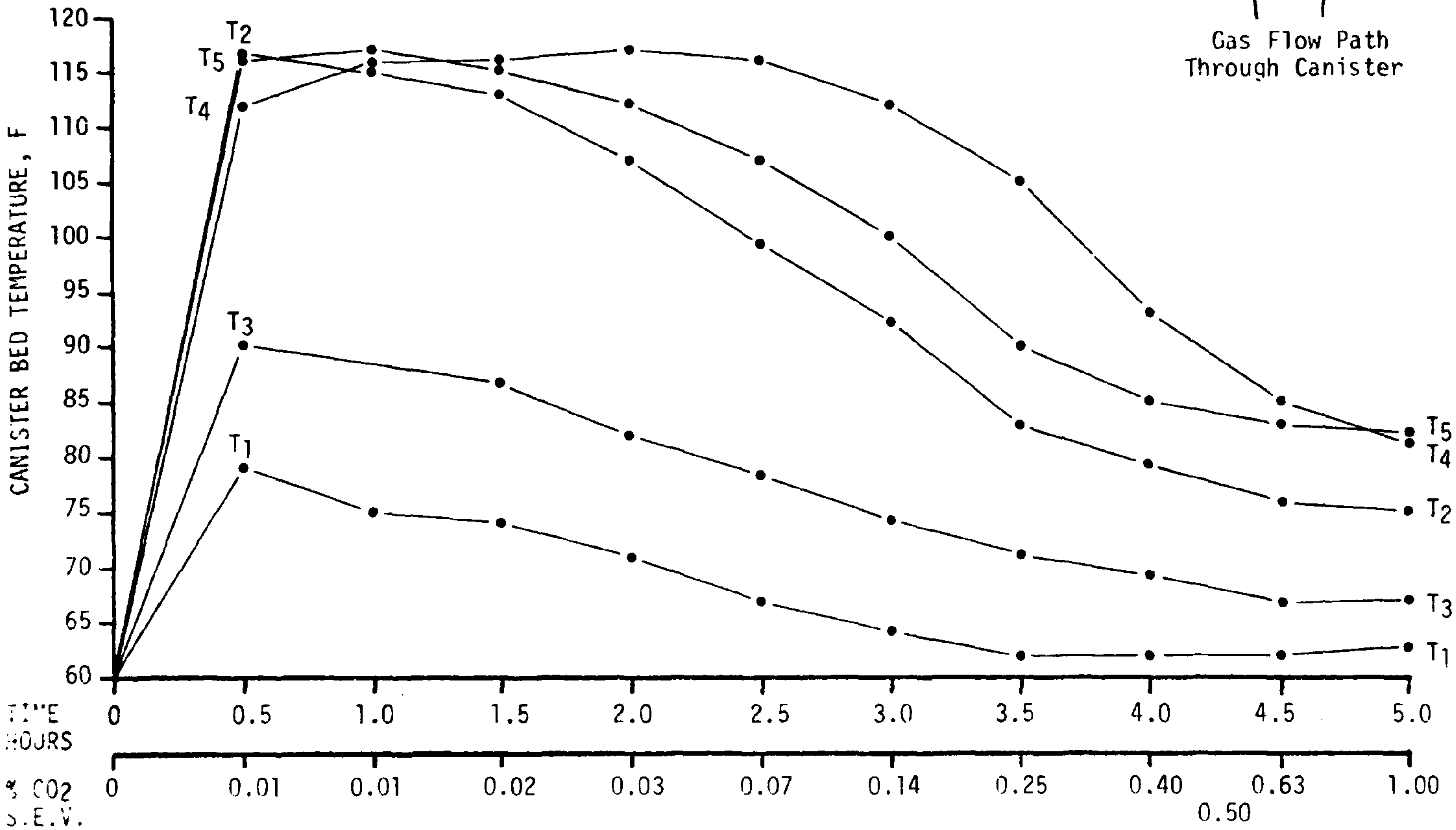


Figure 31. CANISTER BED TEMPERATURES, TEST #4

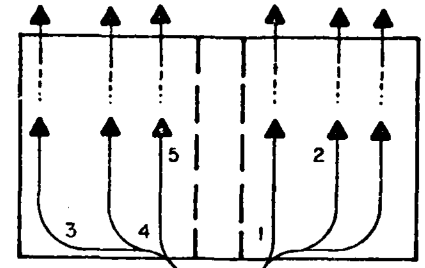
CONDITIONS

Breathing Gas	AIR
H_2O Temperature	35°F
Exh.Gas Temperature	82°F
Exh.Gas Rel. Humidity	90%
Depth	75 FSW
Absorbent Weight	7.32 lb

CANISTER BED DESCRIPTION

Canister bed appears identical to previous test runs (1 and 2) where the top 1-inch layer of absorbent shows no evidence of being used. Slight channeling occurred around outer and inner edges at top.

Location of Temperature Probes (T) in Canister Bed



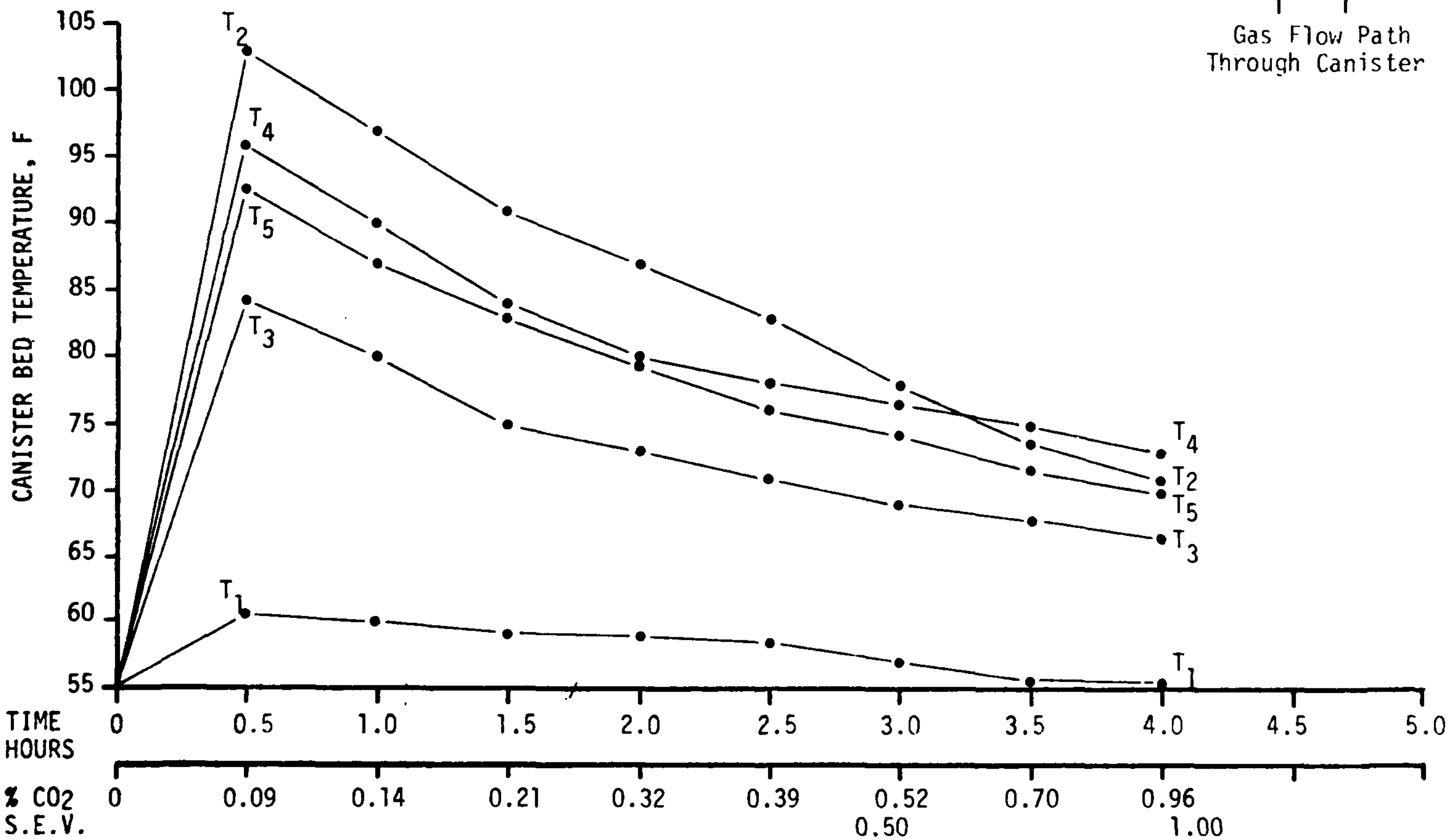


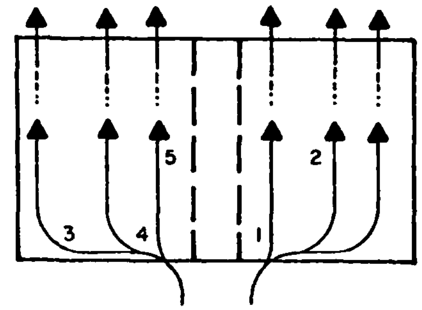
Figure 32. CANISTER BED TEMPERATURES, TEST #5

CONDITIONS		
Breathing Gas		AIR
H_2O Temperature		35°F
Exh.Gas	Temperature	82°F
	Rel. Humidity	90%
Depth		150 FSW
Absorbent Weight		7.32 lb

CANISTER BED DESCRIPTION

Absorbent granules remained all white in color, an indication that the canister's content saw little or no use due to low water temperature.

Location of Temperature Probes (T) in Canister Bed



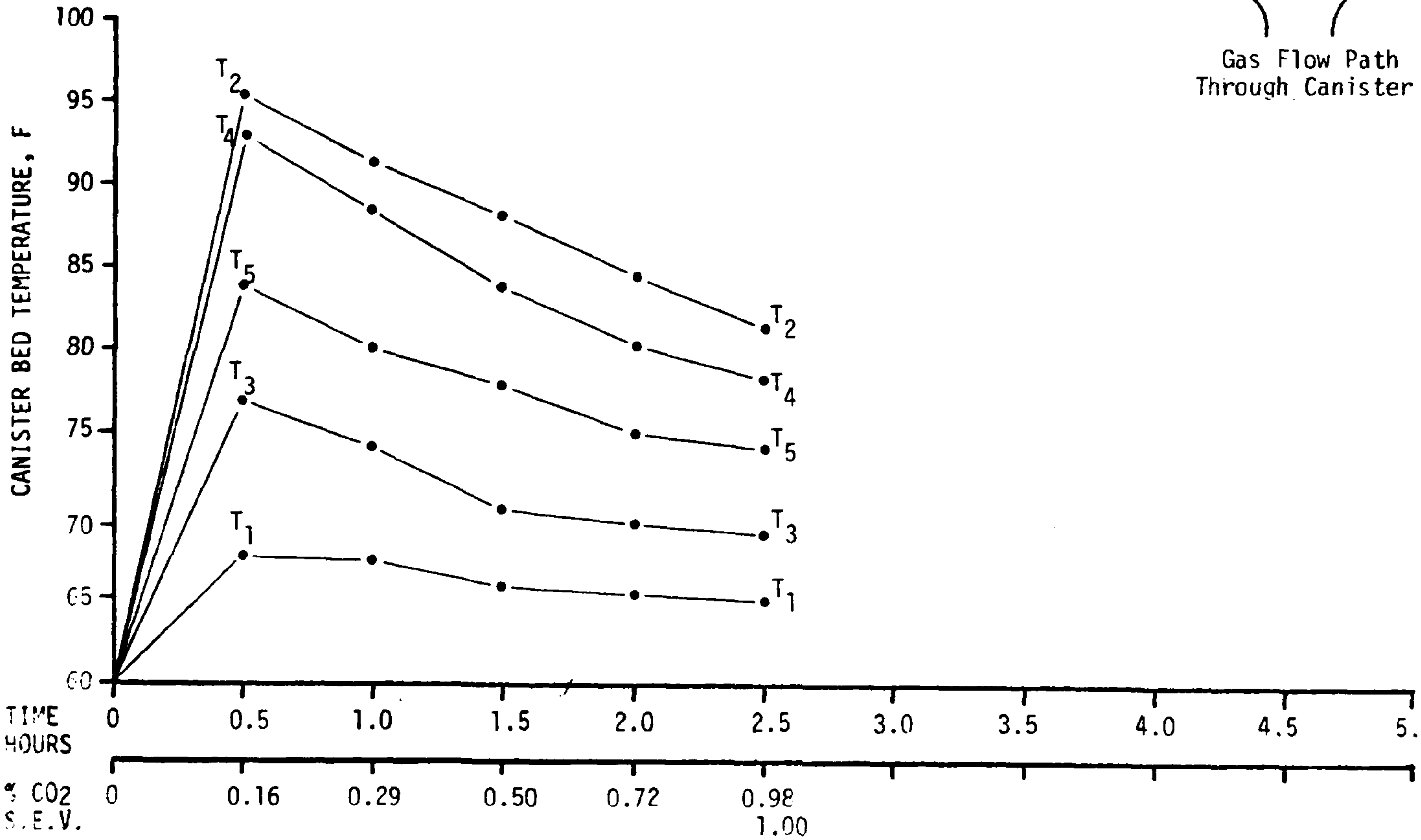


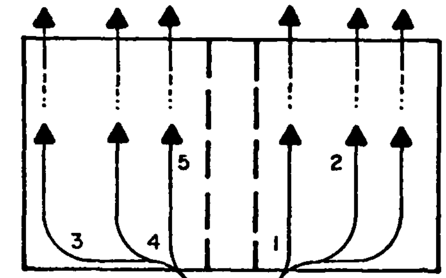
Figure 33. CANISTER BED TEMPERATURES, TEST #6

CONDITIONS

Breathing Gas HeO_2
H_2O Temperature 35°F
Exh.Gas Temperature 82°F
Exh.Gas Rel. Humidity 90%
Depth 300 FSW
Absorbent Weight 7.32 lb

CANISTER BED DESCRIPTION

Canister bed appears identical to previous test run (#7) in that H.P. Sodasorb showed no discoloration and thus indicates poor utilization of the absorbent due to low water temperature.



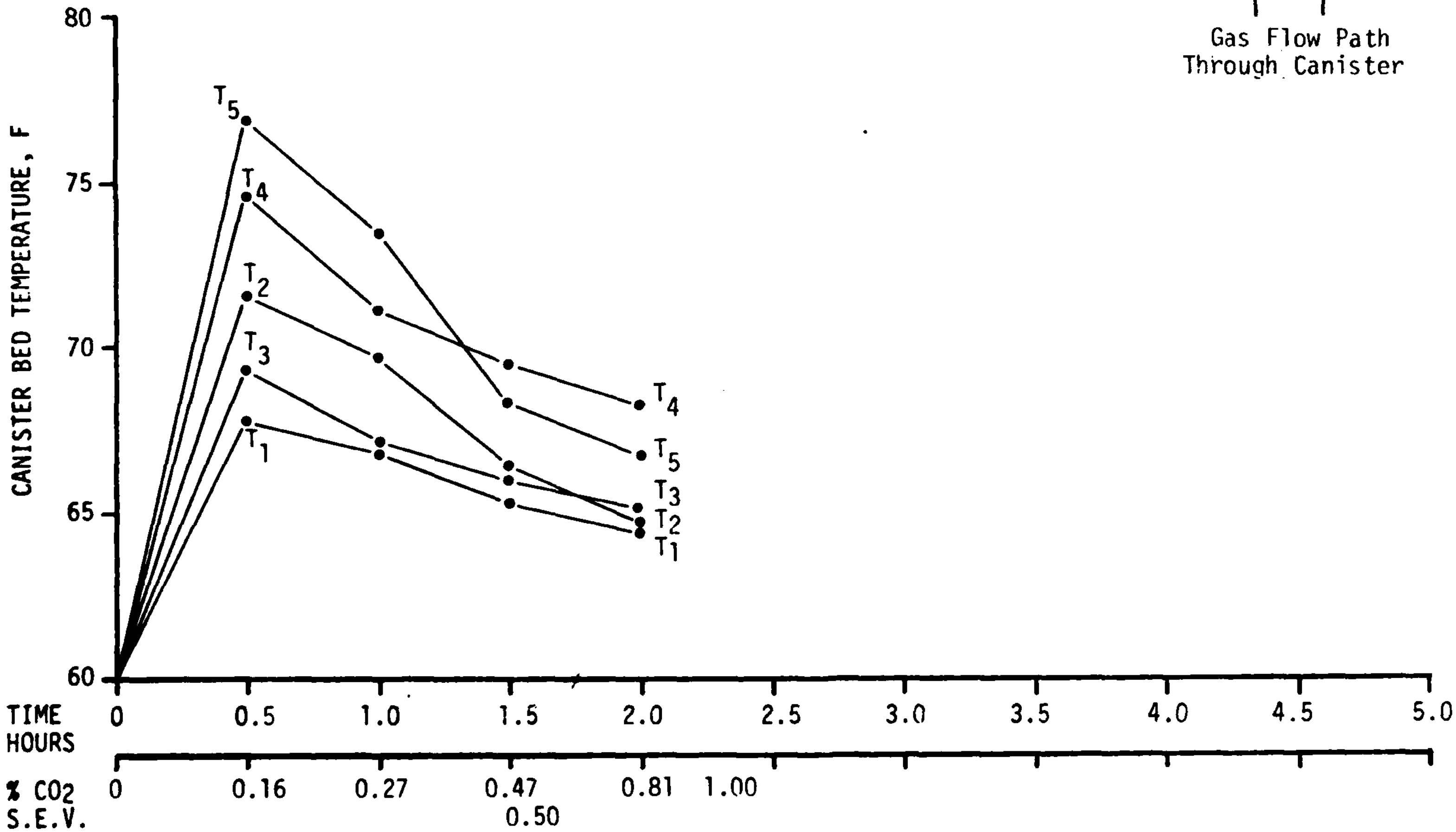


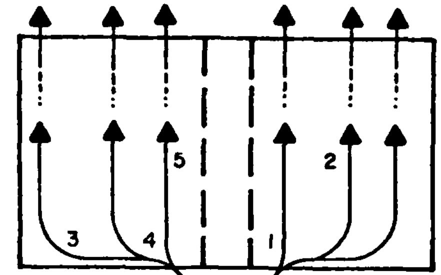
Figure 34. CANISTER BED TEMPERATURES, TEST #7

CONDITIONS	
Breathing Gas	HeO_2
H_2O Temperature	70°F
Exh.Gas Temperature	89°F
Exh.Gas Rel. Humidity	90%
Depth	300 FSW
Absorbent Weight	7.32 lb

CANISTER BED DESCRIPTION

Slight evidence of channeling around inner and outer edges of canister; top layer of H.P. Sodasorb (about one inch) remains white, indicating that it was not used in the CO_2 removal process. Main body of bed uniformly used.

Location of Temperature Probes (T) in Canister Bed



Gas Flow Path Through Canister

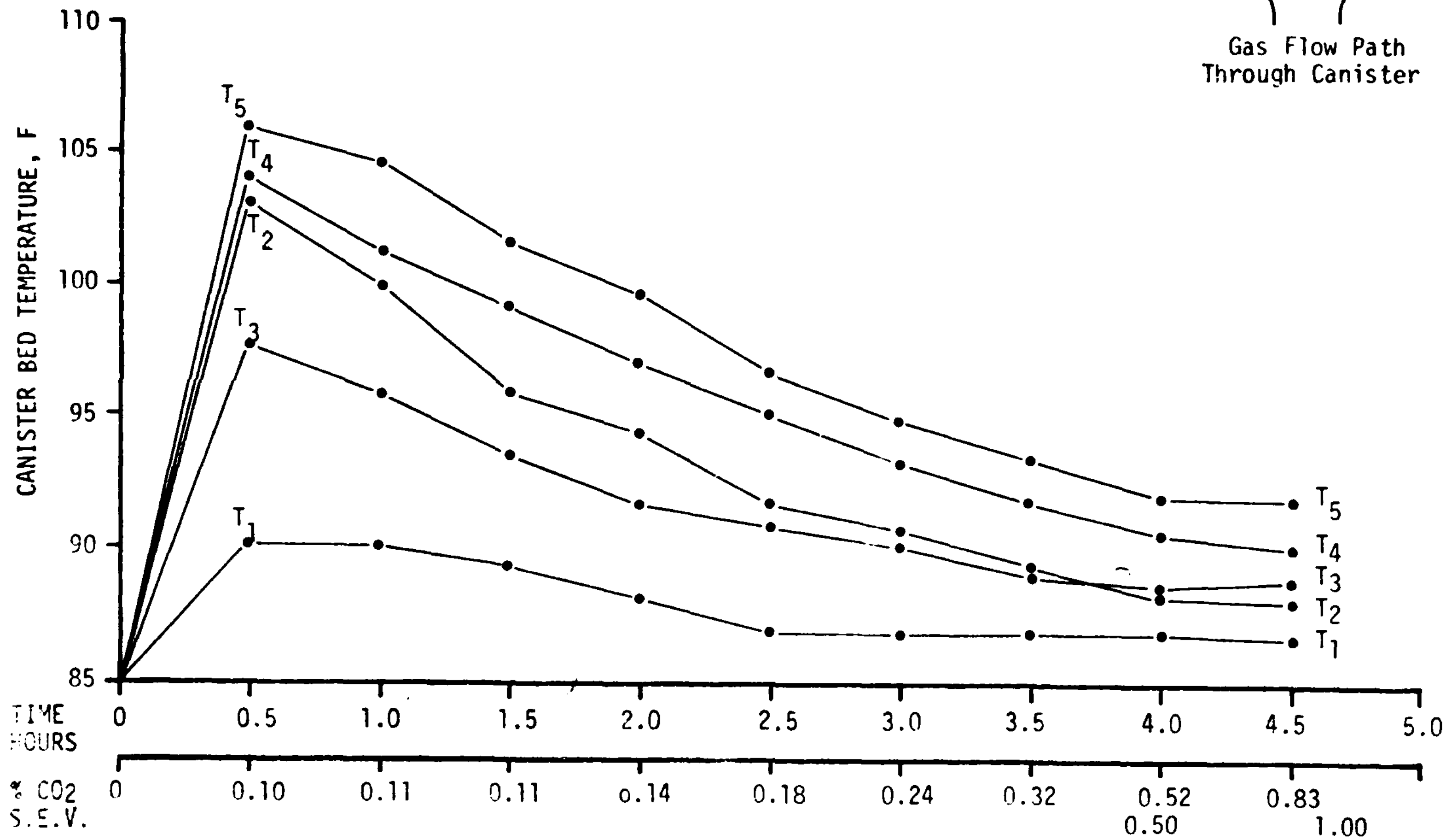


Figure 35. CANISTER BED TEMPERATURES, TEST #8

the absorbent bed is uniformly used. This is verified by the visual descriptions of the used canister bed at the top of each figure.

NOTE

The MK-15 Mod 0 UBA canister was not instrumented for canister bed temperatures.

Canister Duration Tests

Figures 36 through 39 plot percent CO_2 S.E.V. versus time for each of the ten test series conducted. Results are summarized in tabular form in Table 1. Tests indicate a significant improvement in duration over the MK-15 Mod 0 canister at depth. The canister durations, however, follow a typical pattern of decreasing duration as depth increases and water temperature decreases.

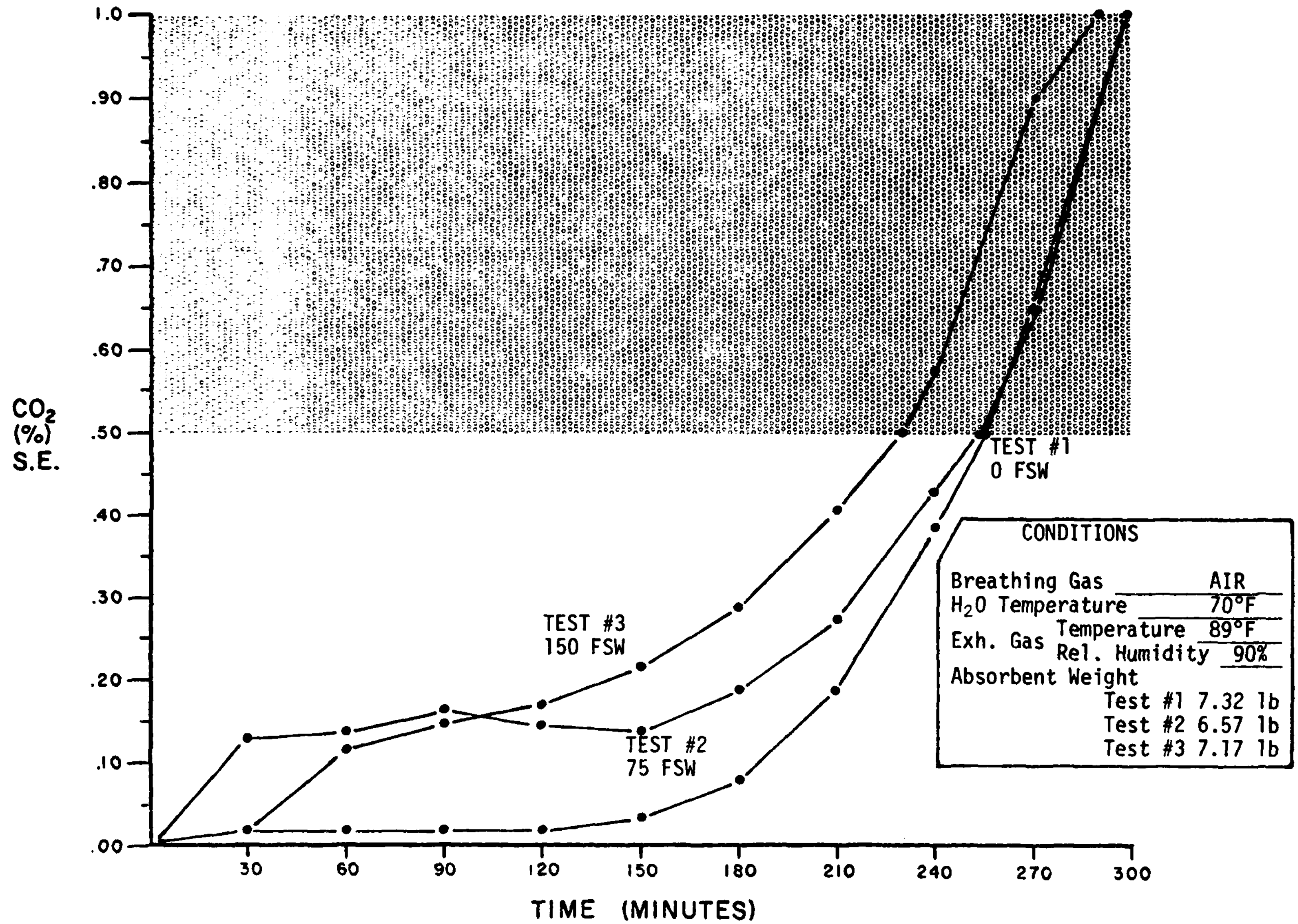


Figure 36. EX-16 UBA CO_2 CANISTER BREAKTHROUGH/DURATION TESTS #1, 2 and 3

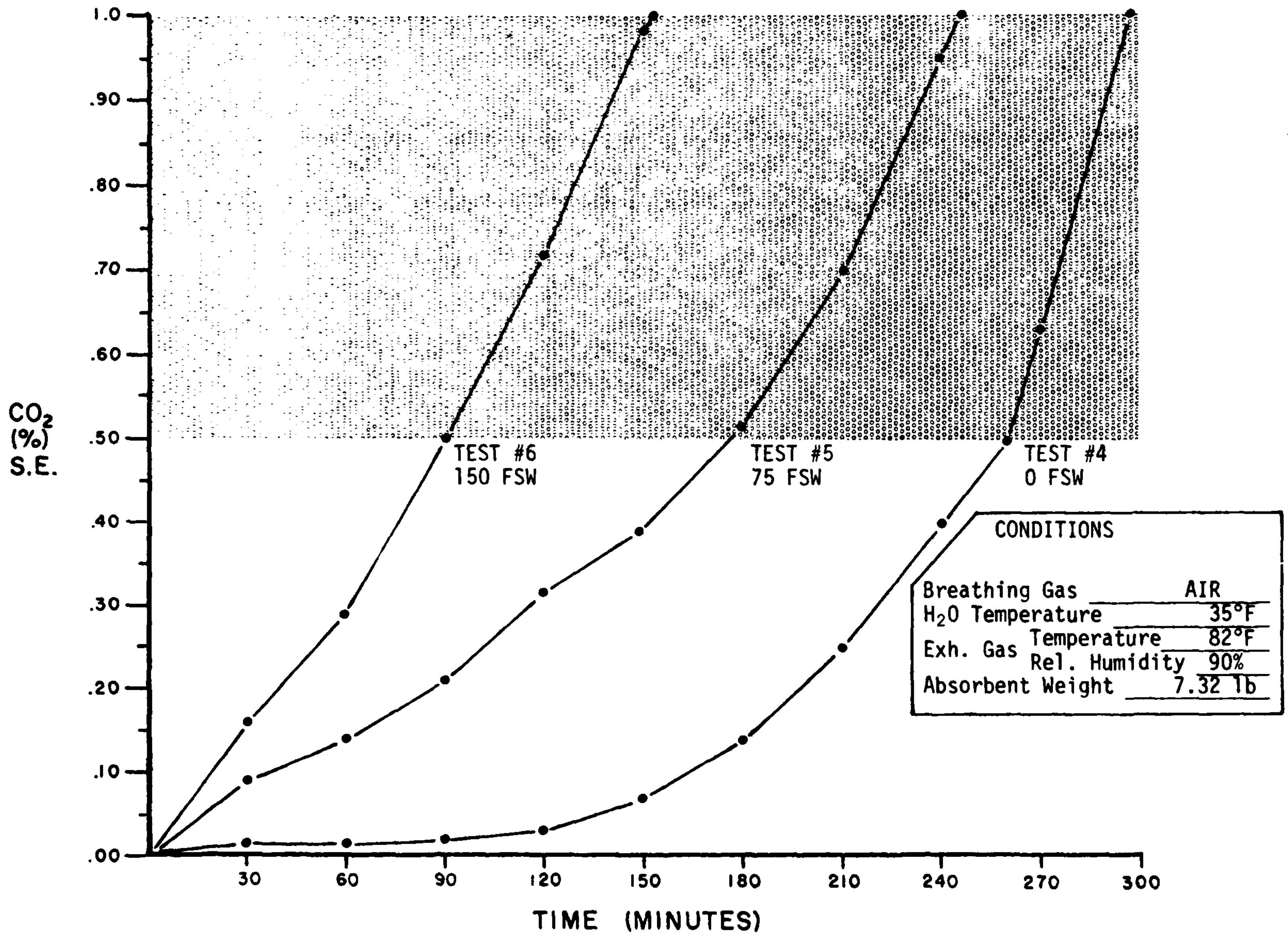


Figure 37. EX-16 UBA CO_2 CANISTER BREAKTHROUGH/DURATION TESTS #4, 5, 6

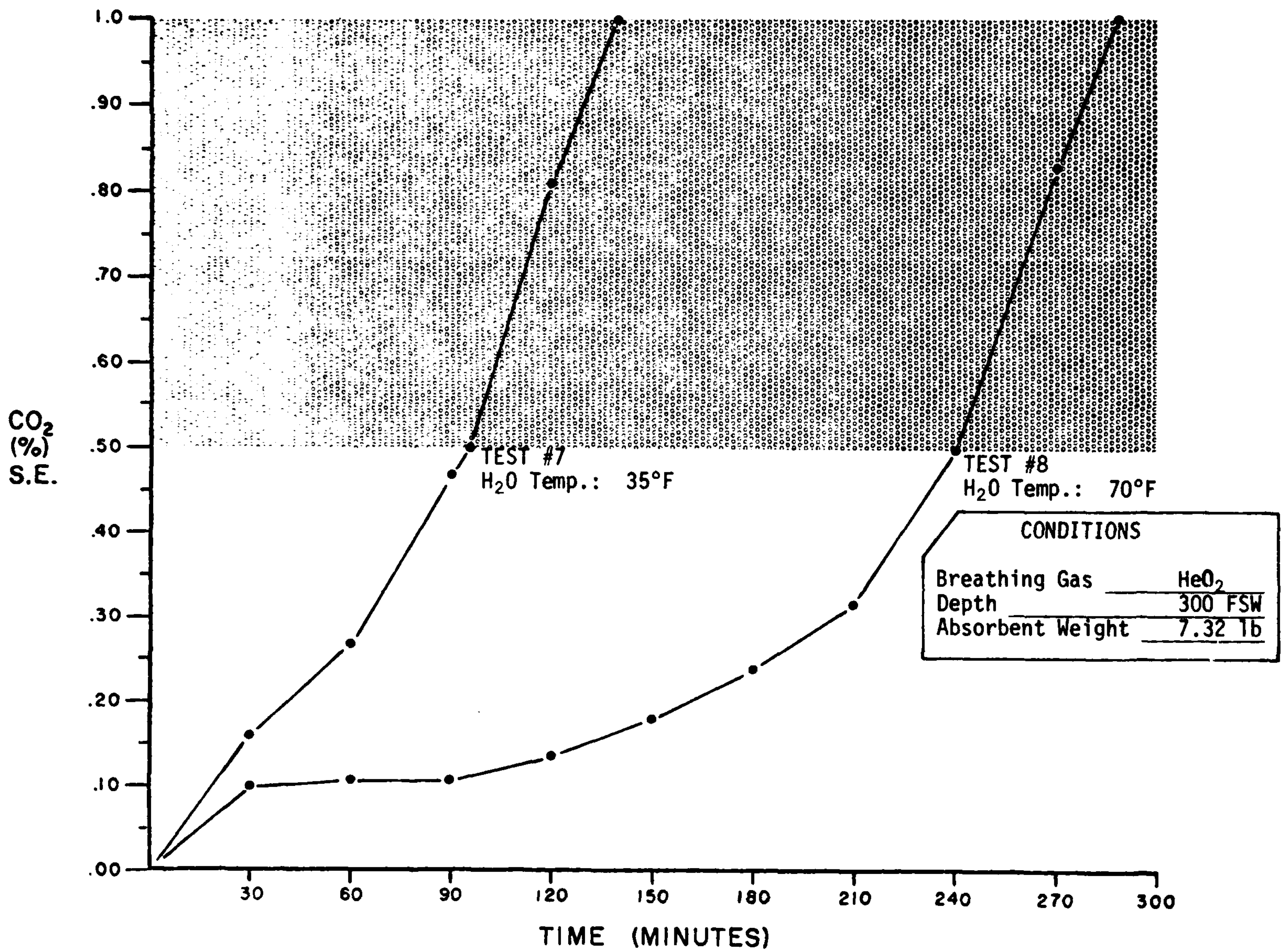


Figure 38. EX-16 UBA CO_2 CANISTER BREAKTHROUGH/DURATION TESTS #7 and 8

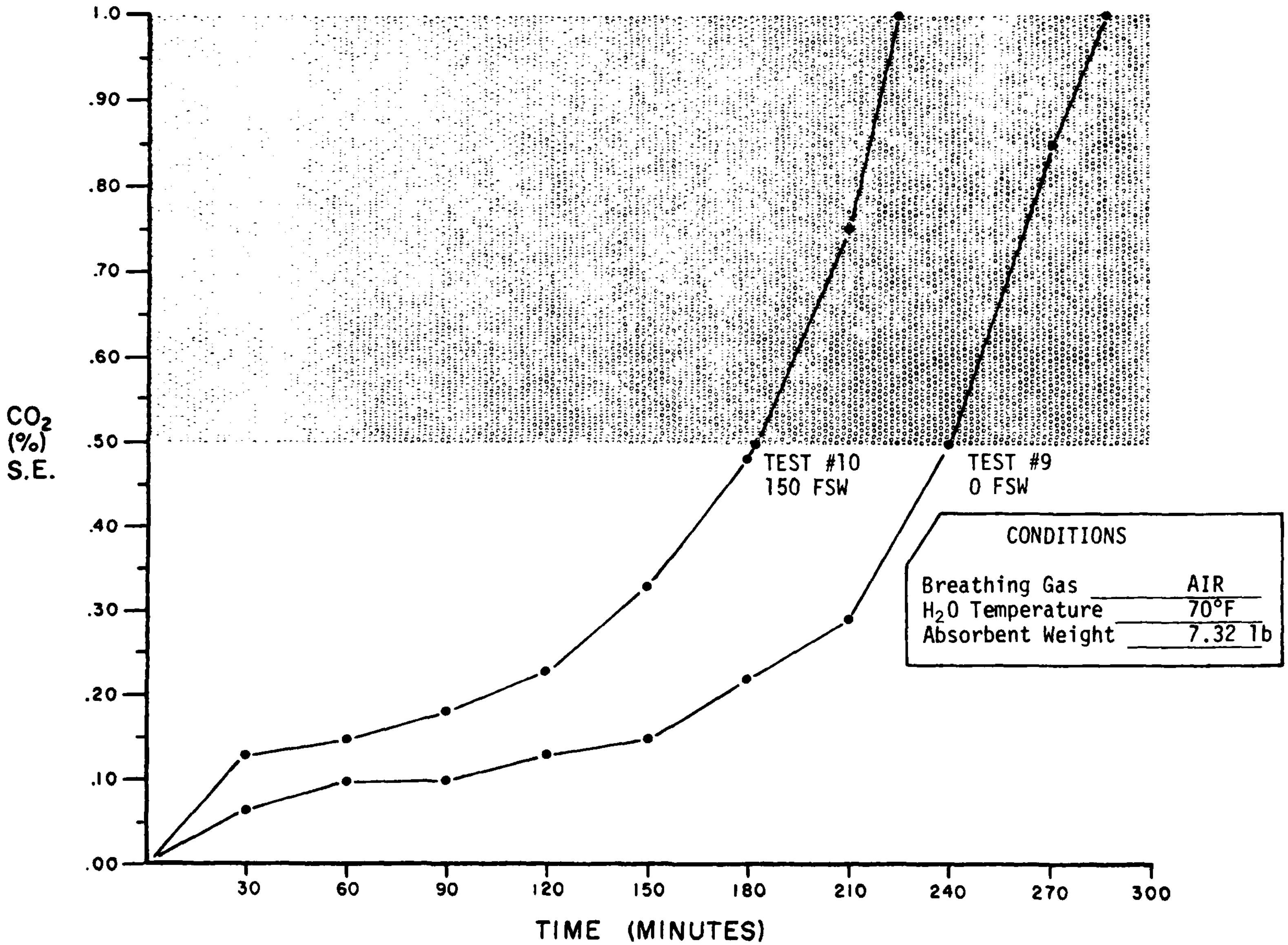


Figure 39. MK-15 MOD 0 UBA CO_2 CANISTER BREAKTHROUGH/DURATION TESTS

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Modifications to the EX-16 UBA resulted in improved functioning. Efforts to reduce breathing resistance produced positive results through enlargement of the breathing hose passages and through addition of the AGA full face mask in lieu of the standard breathing hose/mouthpiece assembly.

A comparison of the breathing work values (kg.m/l) for individual members of the MK 15 family of UBAs shows the AGA full face mask/EX-16 configuration reduces the work of breathing by 38 percent - a considerable improvement. Values shown below are for comparable conditions (75.0 RMV, 150/165 FSW, 70°F Water Temperature, Air).

MK-15 Mod 0 (MK-6 Mouthpiece)	-	0.61 kg.m/l (reference 2)
EX-16 (AGA)	-	0.38 kg.m/l

Analysis of the prototype CO_2 canister temperature gradients and examination of canister bed usage leads to the conclusion that breathing gas flow through the scrubber generally follows a recurring pattern and that the canister bed is uniformly and well utilized. High temperatures at outer, mid- and inner bed locations in the canister further verify uniform canister usage.

RECOMMENDATIONS

The large breathing hoses and AGA full face mask should be considered for use as standard components of the EX-16 UBA. Additional unmanned testing and evaluation of the EX-16 UBA in a preproduction model is recommended.

REFERENCES

1. Department of the Navy Military Specification MIL-R-24169A, Regulator, Air Demand, Single Hose, Nonmagnetic, Divers, March 1967.
2. NCSC Hydrospace Lab Note Number 4-78, 20 April 1978, "MK-15 Mod 0 UBA Breathing Resistance and CO_2 Absorption Tests, Phase II PAT&E."

APPENDIX A

TEST PLAN

1. Test Plan for Breathing Resistance Evaluation

a. (1) Insure that EX-16 is set to specifications and is working properly with standard Scott mouthpiece and hoses

(2) Chamber on surface

(3) Calibrate transducers

(4) Open make-up gas supply valve to test UBA

(5) Adjust breathing machine to 1.5 liter tidal volume and 15 BPM and take readings

(6) Adjust breathing machine to 2.0 liter tidal volume and 20 BPM and take readings

(7) Adjust breathing machine to 2.5 liter tidal volume and 25 BPM and take readings

(8) Adjust breathing machine to 2.5 liter tidal volume and 30 BPM and take readings

(9) Adjust breathing machine to 3.0 liter tidal volume and 30 BPM and take readings

(10) Stop breathing machine

b. (1) Pressurize chamber to 33 FSW

(2) Repeat Steps a-1 through a-10

c. (1) Pressurize chamber to 66-150 FSW in 33 FSW increments

(2) Repeat Steps a-1 through a-10

d. (1) Bring chamber to surface

(2) Check calibration on transducers

e. Repeat Steps a-d to depths of 300 FSW in 33 FSW increments using HeO_2 (84/16) as the diluent

f. Repeat Steps a-e with various combinations of mouthpiece/hose assembly/AGA Mask

APPENDIX A (Continued)

2. Test Plan for CO_2 Canister Duration Evaluation

a. (1) Insure that EX-16 is set to factory specifications and is working properly using H.P. Sodasorb

(2) Chamber is on surface

(3) Calibrate transducers and mass spectrometer

(4) Open make-up gas supply valve to test UBA (Diluent: Air)

(5) Water temperature to be approximately 70°F)

(6) Start humidity add system

(7) Chamber at 0 FSW

(8) Start CO_2 add and maintain following procedure until 2.0% S.E. CO_2 is reached:

4 minutes at 0.9 LPM CO_2 add/2.0 liter tidal volume and 11.5 BPM

6 minutes at 2.0 LPM CO_2 add 2.0 liter tidal volume and 25 BPM

(9) Take data every 15 minutes to breakthrough

b. Repeat Steps a-1 through a-9 at 35°F

c. Repeat Steps a and b at 75 and 150 FSW

d. Repeat Steps a and b using HeO_2 (84/16) as the diluent at a depth of 300 FSW

e. Repeat Steps a and c with MK-15 Mod 0 UBA.

APPENDIX B

TEST EQUIPMENT

1. Breathing machine

2. Validyne DP-15 pressure transducer w/1.00 psid diaphragm (oral pressure, canister pressure drop and inhalation/exhalation hose pressure drops) (4 ea).

3. Wet test box

4. The heating and cooling systems from the EDF life support loop will be used to control water temperature during the canister duration tests.

5. MFE Model 715M X-Y plotter

6. Validyne CD-23 transducer readout (4 ea)

7. Beckman 865 Infrared Analyzer for analysing CO_2 out of scrubber

8. NEDU EDF chamber complex

9. External air supply pressure gauge

10. Chamber depth gauge

11. Test UBA: UBA EX-16

12. Breathing machine piston position transducer/CO_2 add system/humidity add system

13. Hygrodynamics Model 15-3050 Relative Humidity Sensor

14. Gould Brush Model 2600 Strip Chart Recorder

15. YSI Model 731 Thermisters for monitoring canister bed temperature (9 ea)

16. Digitec Model 5820 Thermister Readouts (3 ea)